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Riverlands Site Development

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RIVERLANDS SITE DEVELOPMENT

A Major Qualifying Project Report:

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Degree of Bachelor of Science

By

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Authorship

The authors Devon Ward and Walter Woodington have both contributed to the designs, writing, and editing of this report. Devon contributed the following: Capstone Design Statement, Introduction, History of the Grand Trunk Railway, Overview of Committees Involved, WPI Involvement, Description of Project, Approval Process, Meetings with Client, Site Visits, Trail Design Requirements, Trail Issues, Design Process, Parking Area Design, Hydrological Analysis, Culvert Design Requirements, Culvert Design Process, Hydraulic Analysis, Trail Layout, Required Trail Work, Stormwater Best Management Practices, Parking Lot Design Alternatives, Future Work for Trails, Evaluation of Parking Area Alternatives, Evaluation of Culvert Alternatives, Future Work, Cost Estimations, GIS Maps, AutoCAD Drawings, References. Walter contributed the following: Capstone Design Statement, Introduction, History of the Grand Trunk Railway, Overview of Committees Involved, WPI Involvement, Description of Project, Approval Process, Meetings with Client, Site Visits, Trail Design Requirements, Trail Issues, Design Process, Parking Area Design, Hydrological Analysis, Culvert Design Requirements, Culvert Design Process, Hydraulic Analysis, Trail Layout, Required Trail Work, Stormwater Best Management Practices, Parking Lot Design Alternatives, Future Work for Trails, Evaluation of Parking Area Alternatives, Evaluation of Culvert Alternatives, Future Work, Cost Estimations, GIS Maps, AutoCAD Drawings, References.

Devon Ward

Walter Woodington

Abstract

This project involved the design of a recreational site in Sturbridge, Massachusetts. Designs included the trail surface, erosion controls, a trailhead parking area, and a replacement for a washed-out culvert that crossed the trail. A site survey and hydrological analysis were performed to obtain necessary background data. Two design alternatives for both the parking area and culvert were created and evaluated based on multiple criteria. These alternatives were presented to the Sturbridge Trails Committee and then updated to produce recommendations.

Acknowledgements

The project team would like to recognize and thank several individuals without which this project would not have been possible. We would first like to thank our project advisors, Professor Suzanne LePage and Professor Leonard Albano, for their incredible insight, guidance, and patience throughout this project.

Thanks to Randy Redetzke, Chairman of the Sturbridge Trails Committee, and Tom Chamberland, of the United States Army Corps of Engineers, for devoting their evenings to going on site visits and answering all of our questions.

A special thanks to Richard Ames, GIS Coordinator for the Town of Natick, for his exhaustless knowledge of Geographic Information Systems.

Capstone Design

This project addressed the design constraints as recommended by the Accreditation Board for Engineering and Technology (ABET) to meet the requirements of the capstone design experience for the Major Qualifying Project. ABET General Criterion 3.(c) states "[Engineering programs must demonstrate that their students attain] an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability."[1]

Economic

This project incorporated several economic considerations. Unit cost estimates were developed for trail and parking area materials including gravel, crushed stone, and gates. Additionally, each alternative for the parking area design and culvert design were evaluated based on cost estimates of necessary building materials. While future maintenance costs were not projected for this project, each section was designed to minimize necessary maintenance.

Environmental

The project included designs for an open-bottom and a natural-bottom culvert in compliance with Conservation Commission ordinances. The culverts were sized for a 25-year design storm. The trail was designed to have minimum impact on the surrounding environment by implementing runoff and erosion controls. The designs for trailhead parking incorporated stormwater best management practices to minimize sediment and pollutant runoff associated

[1] Accreditation Board for Engineering and Technology (ABET). *Criteria for Accrediting Engineering Programs*. 2008. Print. <http://www.abet.org/Linked%20Documents-UPDATE/Criteria%20and%20PP/E001%2009-10%20EAC%20Criteria%2012-01-08.pdf>.

with vehicle traffic. The trailhead parking area designs also utilized as much pre-existing clear, level space as possible to minimize the need for tree cutting and excavation of the site. All trail, parking area, and culvert designs were created with consideration to the Massachusetts Wetlands Protection Act and River Protection Act.

Sustainability

One of the most important considerations for this project was the sustainability of the trail to allow for continued usage and enjoyment by the people of Sturbridge and surrounding towns. Sustainability issues addressed included appropriate trail design to minimize or prevent the wash-out of trail materials, and culvert designs that would handle peak flows for a 25-year flood situation. Also taken into account was the ease of access to the trails for necessary maintenance vehicles and equipment for mowing or refinishing the trail surfaces and shoulders.

Constructability

The constructability of the project was hindered by its woodland nature. Special considerations were made to ensure feasible access to the site by construction vehicles and to minimize the impact of construction on the surrounding environment. The excavation and fills required for the trail grading were designed to be of equal volumes, eliminating the need to transfer fill materials to or from the site. The trailhead parking area alternatives were also designed to utilize as much pre-existing level area on the site as possible to minimize expensive and time-consuming excavation. The culvert design recommendations were also evaluated on the ease of excavation and installation of each alternative.

Ethical

This Major Qualifying Project was conducted in accordance to the American Society of Civil Engineers Code of Ethics. The Code of Ethics Fundamental Principles states that "engineers uphold and advance the integrity, honor and dignity of the engineering profession by: using their knowledge and skill for the enhancement of human welfare and the environment; being honest and impartial and serving with fidelity the public, their employers and clients; striving to increase the competence and prestige of the engineering profession; and supporting the professional and technical societies of their disciplines."[2] This project strived to provide the best solutions possible to the parties involved, and does not convey any falsified information or violate any regulations of the governing bodies. This includes but is not limited to the Americans with Disabilities Act and the Massachusetts Wetlands Protection Act.

Health and Safety

The Town of Sturbridge wished to accommodate multi-use of their trail system including bicycles, wheelchairs, and equestrian usage. The trail designs of this project are compliant with all applicable Americans with Disabilities Act regulations. These include Section 4.3, Accessible Routes, and Section 4.8, Ramps, of the Americans with Disabilities Act [3]. The parking area alternatives were designed for user safety by separating trailer parking from passenger vehicle parking. Since the culvert is designed as a bridge for pedestrians as well as

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[2] American Society of Civil Engineers (ASCE). *Code of Ethics*. Web. 27 Apr 2011. <http://www.asce.org/Content.aspx?id=7231#note_2>.

[3] Americans with Disabilities Act of 1990 (ADA). Pub. L. 101-336. 26 July 1990. 104 Stat. 327.

vehicles, the design alternatives included safety guard rails. Both culvert alternatives are designed to meet the American Association of State Highway and Transportation Officials Highway-20 load rating.

Social and Political

The project group held several preliminary meetings with the contacts from the Sturbridge Trails Committee to obtain information for the project and to ensure that all design specifications were met to the satisfaction of the committee. The project group presented preliminary designs at a general body meeting of the Sturbridge Trails Committee to gather feedback and concerns from the members. This input was then used to redesign the alternatives to ensure the best possible design proposal was presented to the Sturbridge Trails Committee for their approval as the governing body on the trail system within the town.

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1 Introduction

Recreational trails can be a valuable part of a community. Dedicated and well maintained trail systems offer a variety of recreational activities to local residents, including hiking, mountain biking, and horseback riding. Properly graded trails can also provide disabled residents access to nature and outdoor recreation that otherwise may not be possible. These unpaved trails create a wealth of opportunities for physical activity, expose people to natures' beauties, and if designed properly can have a minimal impact on the environment.

The Town of Sturbridge, Massachusetts, is seeking to improve and expand their developing public recreational trail system. The Town of Sturbridge owns an undeveloped portion of land adjacent to the Quinebaug River that contains an unfinished section of trail. Local residents and the town government would like to see the quality of the trail improved so that it can meet the standards of the town's existing trail system and the regional trail system that it will become a part of, and also so that it may be fully utilized by the residents. The Sturbridge Trails Committee (STC), the decision-making body for the town's trail systems, requested the aid of a project team of Worcester Polytechnic Institute students to design a portion of trail on what is referred to as the "Riverlands" property.

The goal of this Major Qualifying Project (MQP) was to present solutions to several issues that were preventing the Riverlands Trail from being officially recognized and widely used by the residents of Sturbridge. These issues included the need for a trailhead parking area, proper grading and clearance of the trail surface, replacement of a washed-out culvert that crosses the trail path, and implementation of erosion controls and stormwater best management practices.

The project team obtained information regarding the existing problems of the trail through research of the property, visits to the site, and informational meetings with the project contacts from the Sturbridge Trails Committee. Site visits included a survey of the length of trail and proposed parking area to be designed, flow meter readings at the washed-out culvert during a rainfall event, and observation of the wetland delineation on the site previously performed by the Environmental Protection Agency.

Solutions were designed to meet the requirements of the Sturbridge Trails Committee, as well as comply with all governing regulatory standards. Hydrological calculations were performed from rainfall data for the site using the NRCS Technical Release 55 Manual in order to determine the extent of flow through the culvert crossing. ESRI's ArcGIS software package was used to model the contributing watershed area and aid in the hydrological calculations. From this data, two design options for the culvert were created. Additionally, two designs for the trailhead parking area, as well as a design for the trail length were prepared using Autodesk's AutoCAD program. Preliminary designs were presented to the Sturbridge Trails Committee. Feedback gathered from the meeting was used to improve the designs and ensure that all of the requirements of the Committee were addressed. The designs were evaluated based on cost, constructability, safety, and environmental impact. These criteria aided in selecting which design alternatives were recommended to the Sturbridge Trails Committee.

2 Background

The Town of Sturbridge wishes to develop a portion of land, adjacent to the Quinebaug River, into a recreational trail that will become part of a trail network known as the Titanic Rail Trail. This trail lies on the bed of a historic, uncompleted rail bed known as the Grand Trunk Railway. The project site is locally referred to as the Riverlands site. Following the abandonment of the railway, the site was privately owned and used for storage and as a gravel pit before being acquired by the town. The Sturbridge Trails Committee contacted the WPI Civil Engineering Department to request the assistance of students in completing this project. A culvert that crossed a portion of the existing trail was washed out in 2005, making the trail impassible. The project clients requested a replacement for the washed-out culvert, along with a design for the trail that will meet the Titanic Rail Trail standards, and a design for a parking area that will accommodate visitors to the site.

2.1 History of the Grand Trunk Railway

The Grand Trunk Railway (GTR) was a rail system that operated in the eastern Canadian provinces of Quebec and Ontario, as well as the northern United States, including Michigan and New England. The Grand Trunk Railway operated from 1852 until it was nationalized into the Canadian National Railways in 1923. The GTR consisted of three main branches in Canada and the northern US, and a fourth subsidiary which was never completed. This uncompleted branch was known as the Southern New England Railway, and Palmer, Massachusetts was the proposed location to connect the Central Vermont Railway of the GTR to the warm water ports of Providence, Rhode Island. Construction for the line began in 1910, but was derailed following the death of GTR president Charles Melville Hays in 1912, who fatefully had booked return passage from England aboard the RMS Titanic.

Construction of the Southern New England branch in Massachusetts continued for a while following the death of Hays, primarily so that the contractor could get paid for the work. This resulted in the completion of almost all the grading for the rail bed in Massachusetts, and construction of many of the concrete supports. Many of these concrete structures can still be seen today, as well as large portions of the original grade, winding from Palmer to Franklin, Massachusetts.

Sometime after the railroad project was abandoned a local entrepreneur bought a parcel of land in Sturbridge, Massachusetts, near the Quinebaug River. A portion of the GTR's Southern New England Branch had passed through this property, and the entrepreneur used the site to excavate and sell the gravel fill from the original railway grading for profit. The removal of the gravel ruined portions of the once uniform grade of the rail bed. An example of this gravel removal affecting the grade can be seen in Figure 1. In order to access the gravel on the site, a trail was cut through the vegetation, and a steel pipe culvert was installed to construct a crossing over an area of wetlands that drained into the Quinebaug River. The private owner also used the property as a storage area for construction materials and debris, including concrete rubble, bricks, telephone poles, metal piping, and tires. This dumping is still evident on the property today.


Figure 1: Example of Gravel Removal from Site

The Town of Sturbridge purchased the land from the private owner, and today much of the trail has been reclaimed by vegetation and sits relatively unused. The steel pipe culvert was washed out during a flood in October, 2005, and the trail has been rendered largely impassable. In addition to the Town ownership of the property, there are several easements on the site, including high-tension power lines and a natural gas pipeline which cross the property. A map detailing the parcels owned by the town is shown in Figure 2.

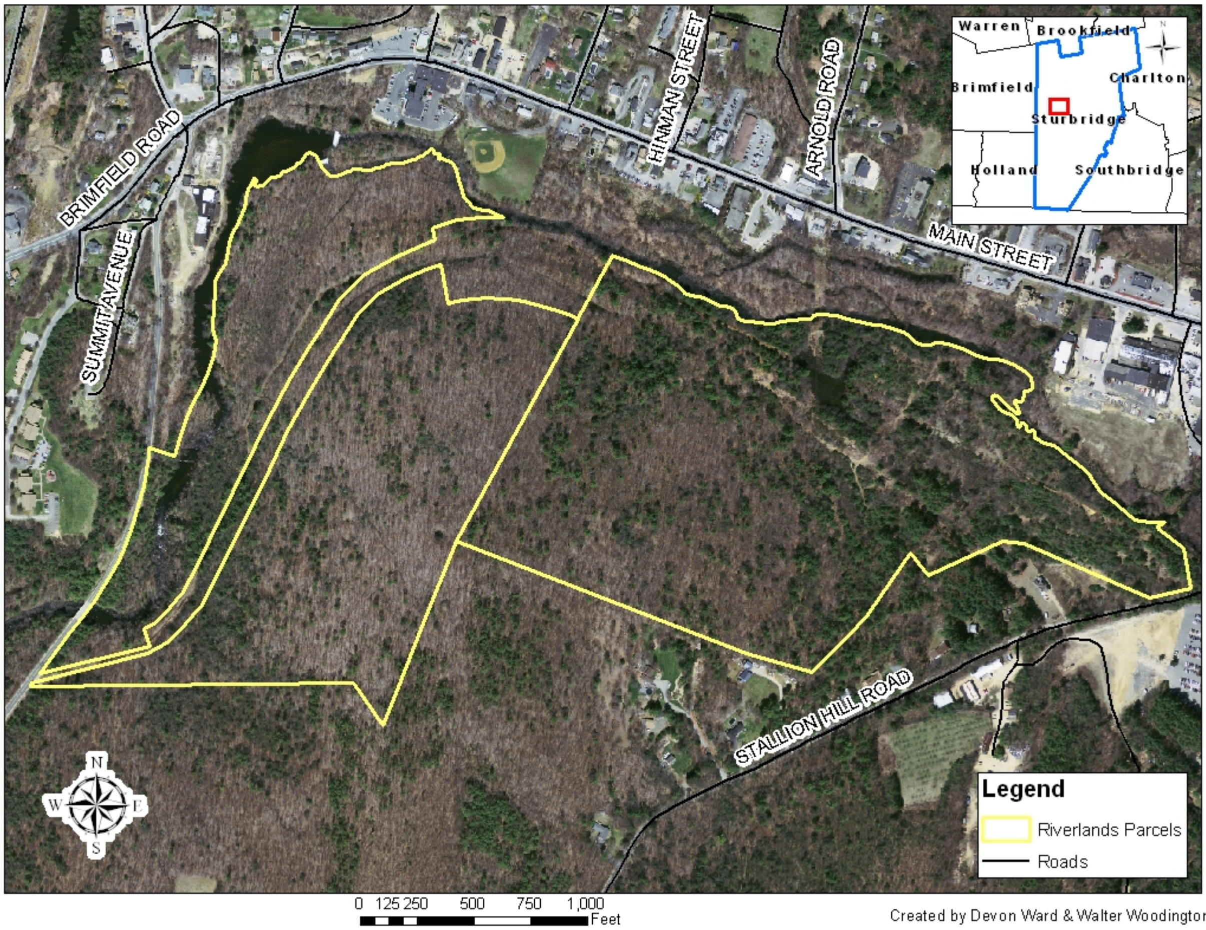

Figure 2: Riverlands Parcels

The town now desires to develop the property into a recreational trail, complete with a parking area for visitors at the entrance to the site. Some development has already begun, including the construction of a maintenance shed located by the entrance to the trail, and concrete pilings for a second shed adjacent to it. An image of the existing shed can be seen in Figure 3.

Figure 3: Existing Shed at Trail Entrance

2.2 Overview of Committees Involved

Multiple public entities were accounted for in the planning of the trail on the Riverlands site. The roles of these public entities are to provide guidance for trail planners, create restrictions to protect the wildlife and environment, look out for the best interests of the town, and standardize trails within the region. Three entities important for this project are the Grand Trunk Trail Blazers, the Sturbridge Conservation Commission, and the Sturbridge Trails Committee (STC). The primary source for design goals and requirements was the STC.

The Grand Trunk Trail Blazers is a nonprofit organization chartered in 1992 to promote and assist in the creation of a non-motorized, 60-80 mile, East-West trail across town boundaries. This trail would link the Blackstone with the Pioneer Valley and be named the Titanic Rail Trail (Grand Trunk Trail Blazers). Their suggestions will guide the design of the Sturbridge trail site to ensure that it can be properly connected to trail segments in other towns and to standardize the trail across town boundaries. A map of the proposed Titanic Rail Trail created by the Grand Trunk Trail Blazers can be seen in Figure 4.

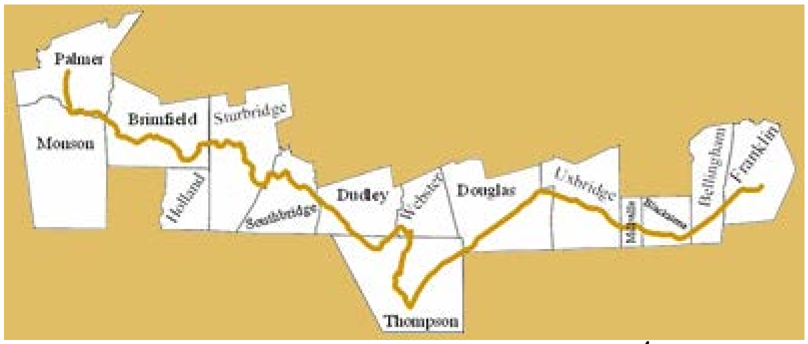

Figure 4: Proposed Titanic Rail Trail Map[4]

The Sturbridge Conservation Commission exists to protect the wetlands, water resources, and the land areas adjacent to water bodies in Sturbridge. To accomplish this, the Commission administers the Massachusetts Wetlands Protection Act (MGL Chapter 131, Section 40), and the Massachusetts Rivers Protection Act (WPA; RPA). This requires the Commission to monitor and review projects, which could have a significant or a cumulative effect on these resources, through an application and permitting process (Sturbridge Conservation Commission).

The Sturbridge Trails Committee, formerly known as the "Regional Trails Committee," oversees the development, design, funding, and future planning of all trails in Sturbridge. It provides guidance for the trail widths, finishing materials, parking area sizes and maintenance requirements. The Committee promotes universal accessibility and also sustainable trail construction techniques in order to encourage usage while minimizing negative long-term effects. The Committee meets monthly and is composed of five voting members and an additional five nonvoting associate members from the town. The Committee also represents the

[4] Grand Trunk Trail Blazers. *Outline Map.* Web. 27 Apr. 2011. http://www.grandtrunktrailblazers.org/images/outline-map-Yellow.png

town on the inter-town “Regional Trails Committee,” which is composed of representatives from Sturbridge, Southbridge, Brimfield, Holland, the US Army Corps of Engineers, and the Grand Trunk Trail Blazers (Redetzke).

The STC has overseen the completion of several trails in Sturbridge and is in the process of planning, developing, and constructing future trails. These projects were made possible through state funding, volunteer labor, and donated work. These completed trail developments served as an indicator of the expected usage of the Riverlands Site and design preferences of the STC (Redetzke).

2.3 WPI Involvement

Contact between the Town of Sturbridge and Worcester Polytechnic Institute (WPI) was first initiated in May of 2009, when Randy Redetzke, the chairman of the Sturbridge Trails Committee contacted Professor Tahar El-Korchi, the department head of the Civil Engineering Department at WPI. The Committee was seeking the assistance of students in developing recreational sites in Sturbridge. It was decided that the description of work required was best suited for a Major Qualifying Project (MQP). This was because the proposed projects required the design of structures in accordance with permitting and regulatory standards, and the consideration of environmental issues and sustainable designs, while lacking in the societal impact that is required for Interactive Qualifying Projects.

Since the contact was made in May, rising seniors had already selected their MQPs for the following school year, and the Sturbridge trail projects were pushed off until the 2010-2011 school year. In March of 2010, Professor Suzanne LePage solicited the project opportunities involving the Town of Sturbridge at the on-campus MQP fair for the Civil Engineering

Department. Two pairs of interested students responded, and a project group was formed. In August of that year further details regarding the projects were explained, and it was determined that the group would be split into two, with one group working on a bridge replacement in the Town of Brimfield, and the other working on the project described in this report.

2.4 Description of Project

The design work required for this project can be divided into three main sections: the recreational trail, the trailhead parking area, and the culvert replacement. Descriptions of the existing conditions for each portion of the designs, as well as background knowledge required for each area of work are explained in the following sections.

2.4.1 Trail

There is an existing cleared path on the project site, which was previously used as an access road by the private owner to remove harvested gravel from the Grand Trunk Railway grading. The STC wishes to develop this into a finished trail. Several obstacles are preventing the trail from meeting the standards of the STC and the Titanic Rail Trail. For instance, the trail features a natural surface which has become overgrown with grasses and trees, and there are erosion problems at certain parts of the trail. The trail may not be wide enough in certain areas to meet the standards required, and may be too steep to accommodate all trail users. The STC wishes for the trail to be accessible for a variety of users, such as pedestrians, bicyclists, equestrians, and wheelchair users. The trail should be finished with an appropriate material to accommodate the expected traffic, but may not be paved.

In order to ensure that the trail design will be accessible to all users, knowledge of the Americans with Disabilities Act (ADA) will be required for this project (ADA). The ADA regulates the guidelines for accessible design, including maximum slopes permissible in various environments, and required safety features. For this project, the ADA will dictate the maximum grade allowed for the design of the trail, as well as the type of acceptable materials that can be selected for the trail surface.

Other regulatory acts that may influence the design of the trail are the Massachusetts Wetlands Protection Act (WPA) and Massachusetts River Protection Act (RPA). These acts are enforced by local Conservation Commissions and set limits on the building activities permissible within buffer zones around wetland areas and rivers. Portions of the trail to be designed for this project may fall within these buffer zones, and additional permitting may be required for construction, or the course of the trail may need to be altered.

Knowledge of stormwater controls commonly used on unpaved recreational trails will be required to design solutions to the erosion problems affecting the existing trail. There are several types of controls employed on hiking and mountain biking trails, and these can be found in trail design guides, such as the Trail Construction and Maintenance Notebook published by the Federal Highway Administration (FHWA-2). Two common water diversion structures are waterbars and grade dips. Waterbars are typically constructed from stones or logs that are placed at intervals along the affected trail and are designed to divert water that hits the obstacle off of the main path of the trail. An example of a rock waterbar construction can be seen in Figure 5.

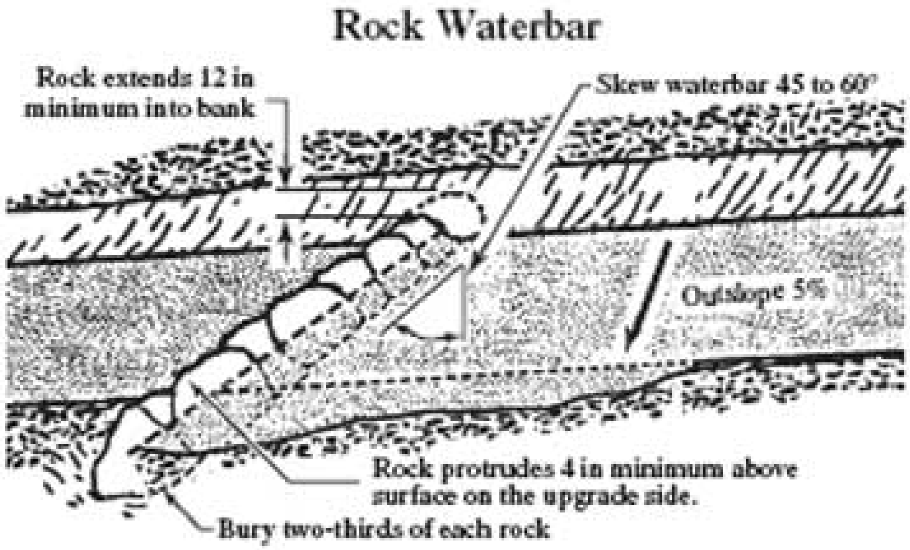

Figure 5: Waterbar Example[5]

Grade dips are the other commonly used erosion control feature on trails. Grade dips are shallow depressions that are placed along trails where stormwater flow is a problem. By dropping the trail surface below the grade of the rest of the trail, excess water is captured and is funneled off the downhill side of the trail by a cross grade that also accompanies the grade dip. An example of a grade dip can be seen in Figure 6.

[5] Federal Highway Administration. *Trail Construction and Maintenance Notebook*. <http://www.fhwa.dot.gov/environment/fspubs/07232806/fig18.jpg>


Figure 6: Grade Dip Example[6]

2.4.2 Parking Area

The STC requested the design of a trailhead parking area at the entrance to the Riverlands site off of Stallion Hill Road. This parking area should accommodate a vehicle volume for the expected usage of the site. There is an extensive, largely flat area near the entrance to the trail that the STC currently keeps clear. A view of this existing space is shown in Figure 7. This is where the existing maintenance shed and concrete pilings for the planned shed are located. This area will be utilized for the parking area to minimize the excavation and clearing required.

To design a parking area, the types and volumes of expected vehicles must be determined. Using this data, the required number of parking spaces, aisle widths, and turnaround radii can be calculated. The guidelines for parking stall dimensions and minimum distances between aisles should be researched for local, state, and ADA requirements. The STC wishes for the parking area to be constructed of a pervious, gravel surface. Pervious materials allow stormwater to infiltrate through the parking surface into the ground and minimize runoff and

[6] Federal Highway Administration. *Trail Construction and Maintenance Notebook*. <http://www.fhwa.dot.gov/environment/fspubs/00232839/figure19.jpg>

pooling problems in the parking area. The usage of cross grading to further decrease pooling should also be explored. In order to assure the gravel surface will sustain the loadings from the expected vehicles, an appropriate design that will not deform or rut under the loads must be created.

Figure 7: View of Cleared Area from Stallion Hill Road

2.4.3 Culvert

There is a washed-out culvert approximately a quarter of a mile from the entrance to the trail from Stallion Hill Road. The culvert connected wetlands to the south of the trail to the Quinebaug River to the north. It was washed out during a flood in 2005 and is now an obstacle, preventing access to and better maintenance of the trail. The washed-out culvert was a three-foot diameter, riveted steel pipe, 27-feet long. The gap formed in the trail grade from the wash out is approximately sex feet deep and 20 feet across. The washed-out culvert can be seen in Figure 8.


Figure 8: Water Flowing around Washed-Out Culvert

The goal of the STC is to replace the washed-out culvert with a durable culvert that will have a minimal impact on the surrounding wildlife and ecosystem. To fulfill this goal, research was performed to gather information about culvert types, hydrology, hydraulics, and structural ratings.

Culverts can be made from many materials, but most frequently from concrete, steel, plastic or any combination of those three. Culverts have multiple applications and therefore come in many shapes and sizes. A summary of these shapes can be seen in Figure 9.

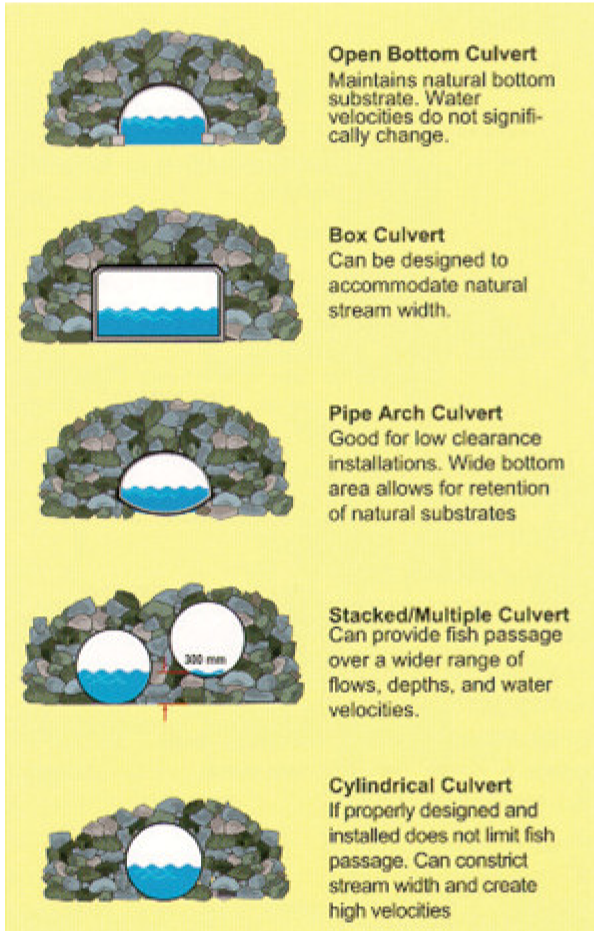

Figure 9: Culvert Shapes[7]

Culverts can be open bottomed, meaning that the bottom of the culvert is entirely composed of natural substrate. If an open-bottomed culvert cannot be used then the Canadian Department of Fisheries and Oceans recommends that the culvert be countersunk and filled with natural substrate (DFO-MPO). An example of a concrete box culvert and a plastic pipe culvert can be seen for comparison in Figures 10 and 11 respectively.

[7] Department of Fisheries and Oceans Canada. *Culvert Installations Fact Sheet* <http://www.nfl.dfo-mpo.gc.ca/folios/00096/images/mtfs_26_ci_1-eng.jpg>

Figure 10: Concrete Box Culvert Example

Figure 11: Plastic Pipe Culvert Example

Knowledge of hydrology and site properties was required to properly size the culvert. This can be performed with the aid of the Technical Release 55 (TR-55) from the Natural Resources Conservation Service (NRCS), which is part of the United States Department of

Agriculture (USDA). The TR-55 presents simplified calculations for storm runoff volume, peak rate of discharge, and hydrographs. The TR-55 is appropriate for small and urbanized watersheds with a 24 hour rainfall distribution (NRCS). Knowledge of hydraulics was required to calculate the behavior of the culvert. The maximum flow through the culvert can be calculated knowing the cross section of the culvert and the properties of the materials that compose the culvert.

Knowledge of structural design guides, manufacturer design guides, and load ratings were required to size and install the culvert. The MassDOT 2005 Bridge Manual outlines the design process for bridges and culverts in Massachusetts (MassDOT-1). Many product manufacturers publish design guides, which assist in the design and promote the uses of their products. These were researched for culvert alternatives. The American Association of State Highway and Transportation Officials (AASHTO) is a standards setting body which creates guidelines and specifications for highways in the United States. AASHTO has standard load ratings which are used to classify the structural capacity of bridges, culverts, and roads.

2.5 Approval Process

The designs from this project will have to go through an approval process before construction on the site begins. A Professional Engineer, the Town Administrator, and the Conservation Commission must all certify and/or approve the design.

A Professional Engineer will have to certify and stamp design drawings for any structures, to ensure human safety and structural soundness. It is the Town Administrator’s responsibility to look out for the best interests of the town and therefore must inspect and approve all plans and developments associated with town property, including any of the development plans recommended for this site. The Sturbridge Conservation Commission administers the Massachusetts Wetlands Protection Act, the Massachusetts Rivers Protection Act and the Town of Sturbridge Wetland Bylaws, Regulations and Policies. Therefore the commission must certify that the site development is in compliance with these regulations (Sturbridge Conservation Commission).

3 Methodology

The designs required for this project were divided into three main sections. These sections were trail design, parking area design, and culvert design. Preliminary meetings were held with the Sturbridge Trails Committee (STC) to obtain design criteria for the respective portions of the project prior to the start of design work. There were also site visits which included an informatory walkthrough with the project contacts as well as data gathering visits. The approaches followed for each of these activities are detailed in the following sections, as well as the steps performed in the design of the trail, parking area, and culvert.

3.1 Meetings with Client

The preliminary method for obtaining the necessary information for this project was through in-person meetings with the project clients. The project team first met with the two main project contacts from the Sturbridge Trails Committee, Randy Redetzke and Tom Chamberland, on September 8, 2010. On this date the project group and advisor Professor Suzanne LePage, were first shown the Riverlands site by Randy Redetzke and Tom Chamberland. This visit focused on familiarizing the project group with the site, and outlined the desired location for the trail-head parking area, as well as the planned path for the recreational trail. The location of the existing storage shed and the washed-out culvert crossing were also shown to the group. Tom Chamberland relayed a brief history of the Riverlands site and the Grand Trunk Railway to the project group during the visit. The site visit allowed the project group to determine the required extents of a site survey, and also provided a starting point for further research into the history of the site and the Grand Trunk Railway.

The project team next met with the project contacts from the STC on September 30, 2010, at the United States Army Corps of Engineers office in East Brimfield, Massachusetts. At this meeting the project contacts explained in greater detail the Committee's future vision for the Riverlands site. This included anticipated usage of the site, and a desire to model it after the Westville Lake Community Trail, which is a very popular recreational site in the area that includes a loop trail and accommodations for picnicking and other recreational activities. Further design requirements for the culvert replacement and trail design were also explained, including the desire for an open-bottom culvert which was anticipated that the Conservation Commission would require. Usage of a 3:1 slope for the culvert reinforcing banks, and the need for guard rails on the culvert crossing were also specified. It was also explained that the trail should be entirely compliant with the Americans with Disabilities Act.

On October 14, 2010, the project group attended a meeting of the Sturbridge Trails Committee where they were introduced to other members of the Committee. The project team briefly explained the anticipated scope of work for the project, which included designs for the parking area, culvert, and the trail length from Stallion Hill Road to the gravel pit on the site. The STC debated on whether the initially planned finished width of sixteen feet was required as many of the towns' "secondary" trails were not that wide. After deliberation it was decided that the trail on the Riverlands site must comply with the rest of the Titanic Rail Trail system.

The project group attended a second meeting of the Sturbridge Trails Committee on January 13, 2011. The project group presented a PowerPoint to the Committee that included an overview of the work performed up to that point, preliminary design alternatives for the trailhead parking area, and a list of questions that had arisen during the design process. This PowerPoint presentation is located in Appendix B.

The STC made comments and provided feedback on the preliminary parking area designs presented, which enabled the project group to make revisions and continue working towards final design recommendations that would meet the goals and requirements of the committee. The Committee also answered several questions the project group had encountered thus far in the project, and the new information was incorporated into further designs.

3.2 Site Visits

Extensive knowledge of the Sturbridge Riverlands site was required to begin designing solutions to the problems presented by the STC. The information necessary to progress with design work was obtained by the project group through several visits to the site. These various visits are detailed in the following sections.

3.2.1 Site Walk

Following the first guided tour of the Riverlands site by Tom Chamberland and Randy Redetzke on September 8, 2010, the project group returned to the site to gather more information on September 22, 2010. During this site visit the project group further familiarized themselves with the layout of the site, including the location of high-tension wires and a natural gas pipeline that cross the site. Other information obtained from this visit included identification of areas with visible stormwater erosion problems, the extent of on-site litter and man-made debris, and where motorized vehicles had gained access.

3.2.2 Site Survey

A survey of the Riverlands site in Sturbridge was performed over two site visits to obtain the necessary layout and gradational data required for the project. A Topcon GTS-605 Total Station and a Topcon FC-2500 data collector were used to conduct the survey. The centerline of the existing trail path was surveyed for location and grade in order to create an accurate plan view of the trail and to determine the differences between existing conditions and ADA compliance. The extent of usable, level space at the entrance of the property for trailhead parking was also surveyed to determine boundaries of the parking area without requiring hillside excavation. Survey distances from the centerline of the trail to the bank of the Quinebaug River were obtained to determine the extent of the trail that fell within the 200-foot buffer zone mandated by the Massachusetts River Protection Act (RPA, Chapter 258).

3.2.3 Wetland Delineation

A walk-around of the entire property owned by the Town of Sturbridge showed that the wetlands on the property had previously been delineated and flagged by the Environmental Protection Agency (EPA). The existing flagging was deemed sufficient by the project group for the purposes of the project. The flagging on the site was then compared to the MassGIS wetland layer for the area using ArcGIS, and it was decided that the MassGIS layer was accurate enough for use in the designs of the project.

3.2.4 Rainfall Event Flow Data Collection

On the morning of November 17, 2010, the project group visited the Riverlands site during a rainfall event. A Gurley Pygmy Current meter (model 625D) was used with a Gurley Flow Velocity Indicator (model 1100) to measure the velocity of the flow through the washed-out culvert location on the trail. Data was recorded across the channel at various stages. Rainfall data for the storm event was obtained from the National Oceanic and Atmospheric Administration's (NOAA) Worcester Regional Airport records (NOAA-1). This data was then used to compare the flows observed at the culvert crossing to those expected for a similar storm using the Technical Release 55 manual's methods (NRCS). The collected data and comparison is presented in the Hydrological Analysis, Section 3.5.1. This visit to the site also allowed the project group to observe the extent of wetland storage. By following the flow through the culvert upstream the project group determined the source of flow onto the site, and where the flow entered the wetland area adjacent to the culvert crossing. Figures 12 and 13 contain images of the site from the day of the rainfall event.


Figure 12: Box Culvert Leading into Wetlands on the Site


Figure 13: View Immediately Upstream of Washed-Out Culvert

3.3 Trail Design

The methodology of the trail design covers research and identification of design requirements, the categorization of the trail by issues found, and describes the design process. The application and results of this process can be seen in the Results, Section 4.1.

3.3.1 Trail Design Requirements

The design requirements for the trail portion of the project were obtained from meetings with The Sturbridge Trails Committee and e-mail correspondence with the project contacts. Many of the design requirements were based on various regulatory statutes, including the Americans with Disabilities Act (ADA), The Massachusetts Wetlands Protection Act, and The Massachusetts River Protection Act. These requirements are summarized in Table 1 below.

Table 1: Trail Design Requirements and Sources

Design Area	Source	Requirement
Trail Cross Section	Titanic Rail Trail Standard	10 foot main trail 2 and 4 foot shoulders
Grading	Americans with Disabilities Act (ADA)	Maximum 5% grade for 200 feet Maximum 8% grade for 80 feet[8]
Stormwater Controls	Sturbridge Trails Committee	User safety Low Maintenance
Development Near Protected Wetlands	Mass. Wetlands Protection Act	New Development should not interfere with vegetation or wild life.[9]
Development Near Protected River	Mass. River Protection Act	200 foot buffer between river and trail

[8] ADA, Section 4.3, Section 4.8
[9] Regulations for the Wetlands Protection Act, 87-90

3.3.2 Categorization of Trail Issues into Sections

In order to design a trail within the requirements, site visits were conducted to collect information about the trail properties. Width and length were measured and were used for cost and material estimation purposes. Site visits were also used to identify the existing issues preventing the compliance of the trail with the design requirements. They were categorized into four main issues clearing, grading, stormwater, and boundary conditions. These categories were used to break the trail into sections along the length. A map of the trail showing the sections and issues are presented in Figure 14. The issues are then summarized by section in Table 2.

Section one begins at the trail head at the parking area off of Stallion Hill Road. The succeeding sections are numbered in order along the length of the trail. The culvert crossing forms the boundary between sections two and three. Section five ends at the gravel pit on the Riverlands site.

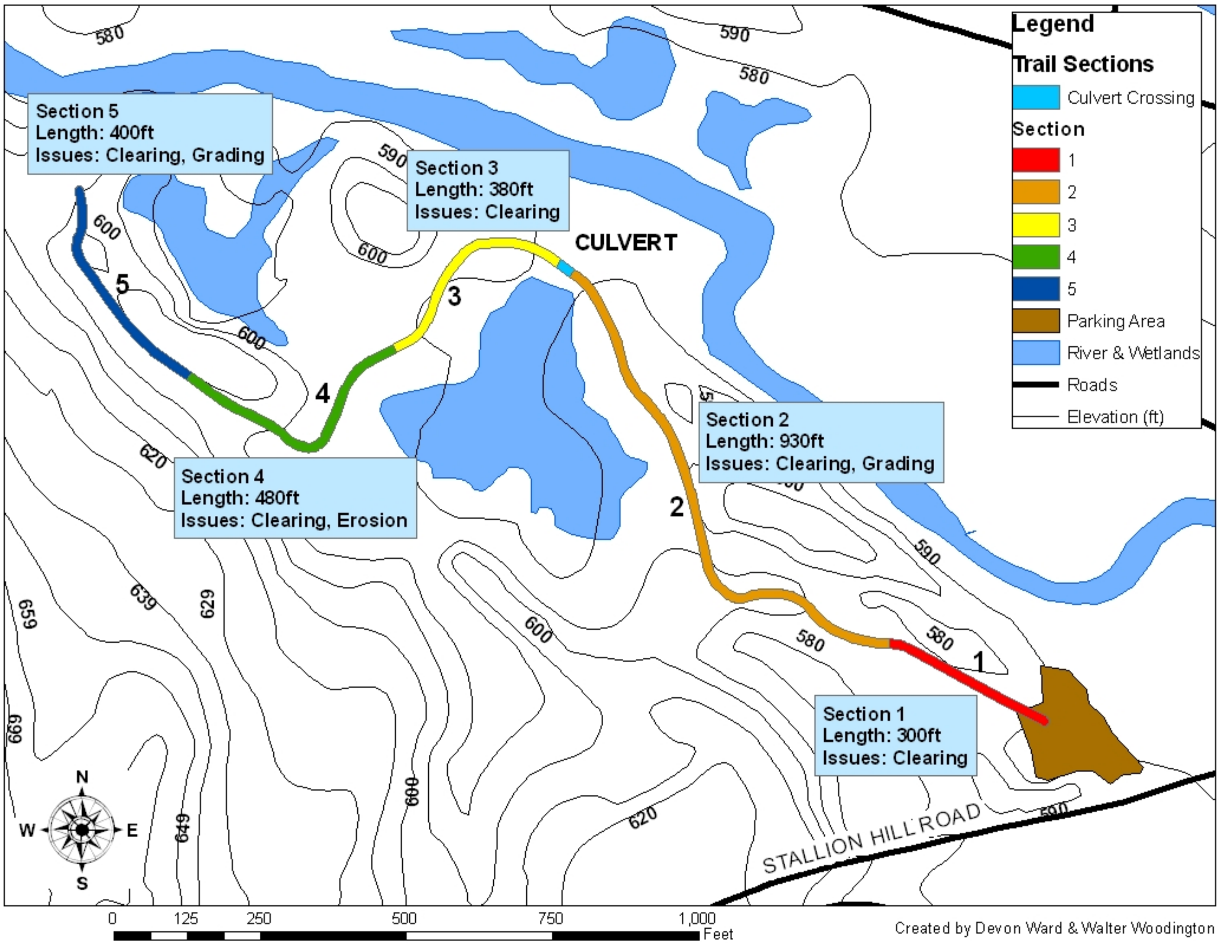

Figure 14: Trail Sections & Issues

Table 2: Trail Issues & Lengths by Section Number

Section	Length	Design Issues
1	300	Clearing, Boundary
2	930	Clearing, Grading, Boundary
3	380	Clearing, Boundary
4	480	Clearing, Stormwater, Boundary
5	400	Clearing, Grading, Boundary

Sections identified as having clearing issues will require extensive cutting of trees and foliage and/ or filling and ground work to achieve a useable trail width of 16ft. Sections identified as having grading issues are not compliant with the slope and length requirements of the ADA (ADA, Section 4.3, Section 4.8), or are of an undesirable grade to allow for a wide range of uses. Excavation and fills will be required to achieve this. Sections identified as having stormwater issues were found on site visits to have evidence of erosion or scouring of the trail as well as flows of water on the trail during rain events. Stormwater best management practices will be used to combat this deterioration of the trail as well as pooling which can lead to mucky, unusable trail surfaces. Lastly, boundary issues refer to sections of the trail that are expected to be within the protected areas surrounding the wetlands and the Quinebaug River. This can be prevented by changing the course of the trail or can be resolved with permitting though the Sturbridge Conservation Commission.

3.3.3 Design Process by Issue Category

Clearing issues were determined to be extensive on the site visits and affecting the entire trail. Before the trail construction can begin, the flagging and felling of trees as well as ground work will be required to create a useable 16-foot wide trail area.

Grading issues along the trail were expected in sections two and five from the site visit. The actual issue areas were located using an elevation model created in AutoDesk's AutoCAD. This model was built by first importing the survey data points taken along the trail into Microsoft Excel then finding the average slope between consecutive points. These slopes were compared against the requirements from the ADA. Solutions were created using the AutoCAD model to improve the grade of the trail so it will be both ADA-compliant and usable for a wide range of people and activities. An elevation profile of the trail with detailed information about excavation and fill areas can be seen in the Results, Section 4.1.2.

Stormwater issues were observed in section four on the site visit. Research was performed to find solutions to the runoff issues using trail design guides suggested by the

Sturbridge Trails Committee. Three alternative methods for shedding water off the trail were evaluated, including water bars, grade dips, and cross grading. These stormwater controls are compared in Table 3.

Table 3: Stormwater Controls Comparison

Method	**Advantages**	**Disadvantages**
Water Bars	- Easy to install - Can be design for high flows - Resists traffic wear	- Collect debris and clog - Not handicap accessible - Obtrusive to wheeled traffic
Grade Dips	- Easy to maintain - Unobtrusive	- Must be reinforced for high flows - Excavation is required for construction
Cross Grade	- Easy to maintain - Unobtrusive	- Excavation is required for construction - Not effective for high flows

Boundary issues occur on areas of the trail; meaning that the sections lie within buffer zones defined by The Massachusetts Wetlands Protection Act or The Massachusetts River Protection Act (WPA; RPA). These issues were expected on all sections from the site visits because of the proximity of the Quinebaug River and the wetlands to the trail. These Acts dictate the boundary distance from rivers and wetlands in which development is restricted.

The Massachusetts River Protection Act requires permitting for any site alteration within the 200ft riverfront area (RPA, Chapter 258). The Massachusetts Wetlands Protection Act requires “environmentally sensitive site design” and “low impact develop techniques” to be used on any development within 200ft of wetlands (Regulations for the Wetlands Protection Act, 87-90). The use of these is monitored by a review process but can be simplified or avoided if the project fits certain criteria outlined in the CMR Preface Appendices (Regulations for the Wetlands Protection Act).

Permitting though the Sturbridge Conservation Commission according to The Massachusetts Wetlands Protection Act and The Massachusetts River Protection Act will also be required before any construction can begin within this buffer zone. The permitting process is out of the scope of this MQP and will be handled by The Town of Sturbridge.

The ESRI ArcGIS software package was used to graphically determine the boundary areas for the wetlands and the river. Sections two three, four, and five are within the required 200ft of the wetlands. Trail sections one, two, three, and five are within the required 200ft of the Quinebaug River. Figure 15 shows the extent of the 200ft buffer zone from the river.

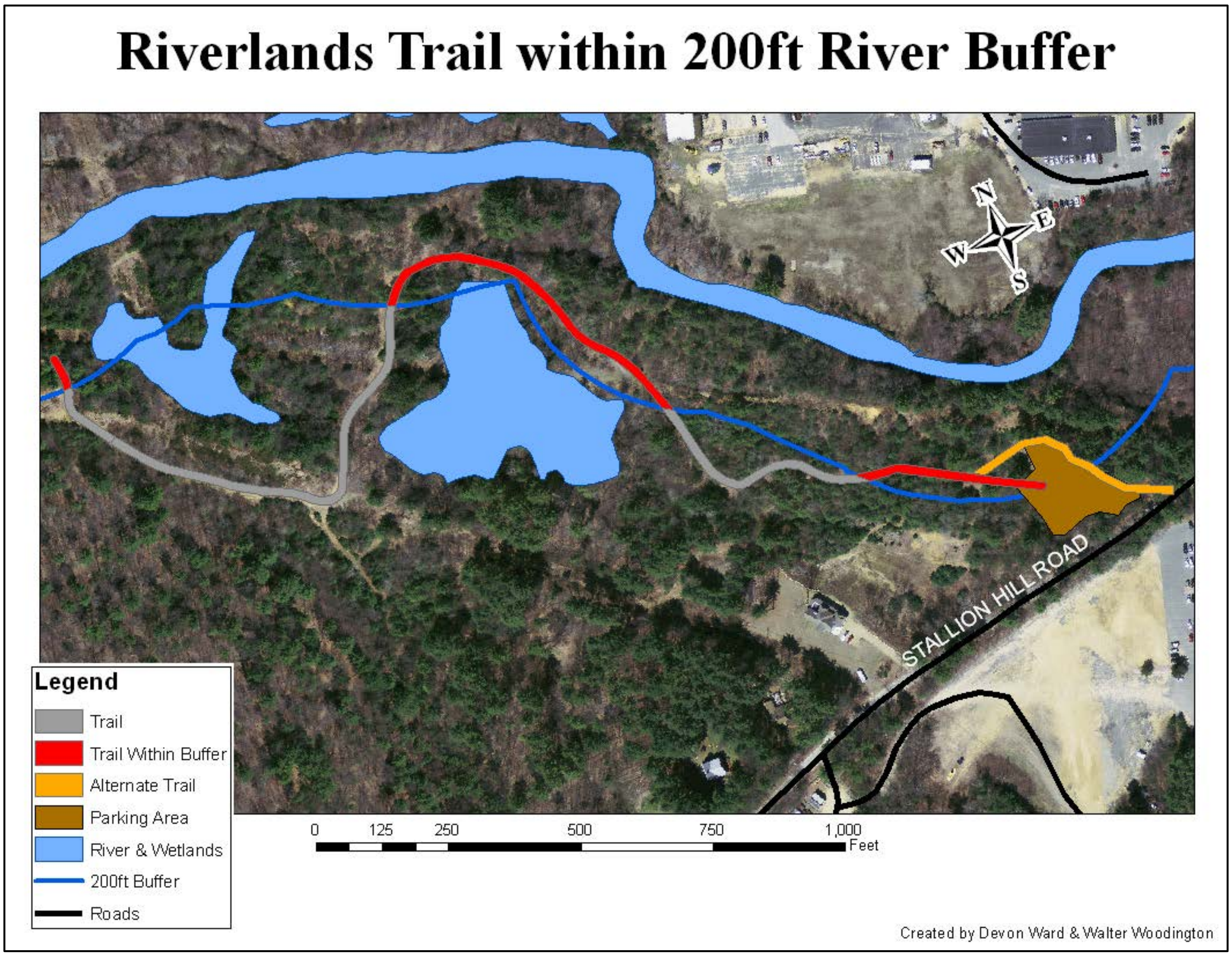

Figure 15: Trail within 200ft River Buffer

3.4 Parking Area Design

The STC expressed a need for a trailhead parking area at the entrance to the Riverlands Trail site on Stallion Hill Road. Initial design requirements expressed from the project contacts on the Committee included parking for 25 to 30 vehicles, a trailer turnaround area, and a storage area for maintenance materials. Additionally, the STC requested that the existing storage shed not be moved if possible, and to have a separate walking trail that doesn't pass through the parking area. These criteria, as well as data gathered from the site survey, formed the basis for the preliminary parking area designs. The survey included the extents of the existing clear, level area at the entrance to the trail off of Stallion Hill Road. These survey points were imported into AutoCAD and ArcGIS.

Preliminary Designs

Two preliminary parking area designs were created in AutoCAD to incorporate different aspects of the initial design criteria. These two designs are shown in Figures 16 and 17. The varying features of the two design alternatives are presented in Table 4. These preliminary designs were presented to the STC at their meeting on January 13, for feedback and revisions.

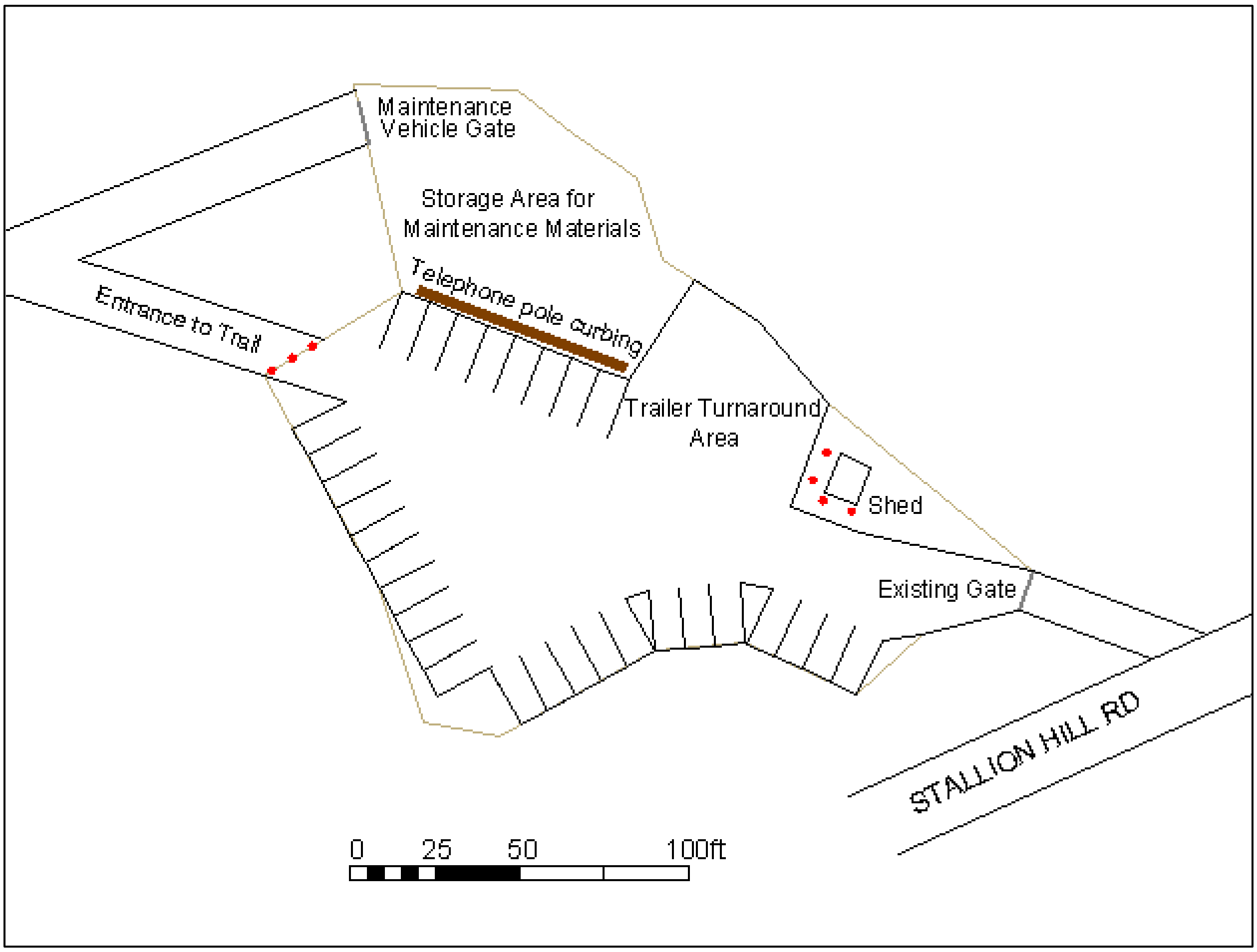

Figure 16: Preliminary Parking Area Design 1

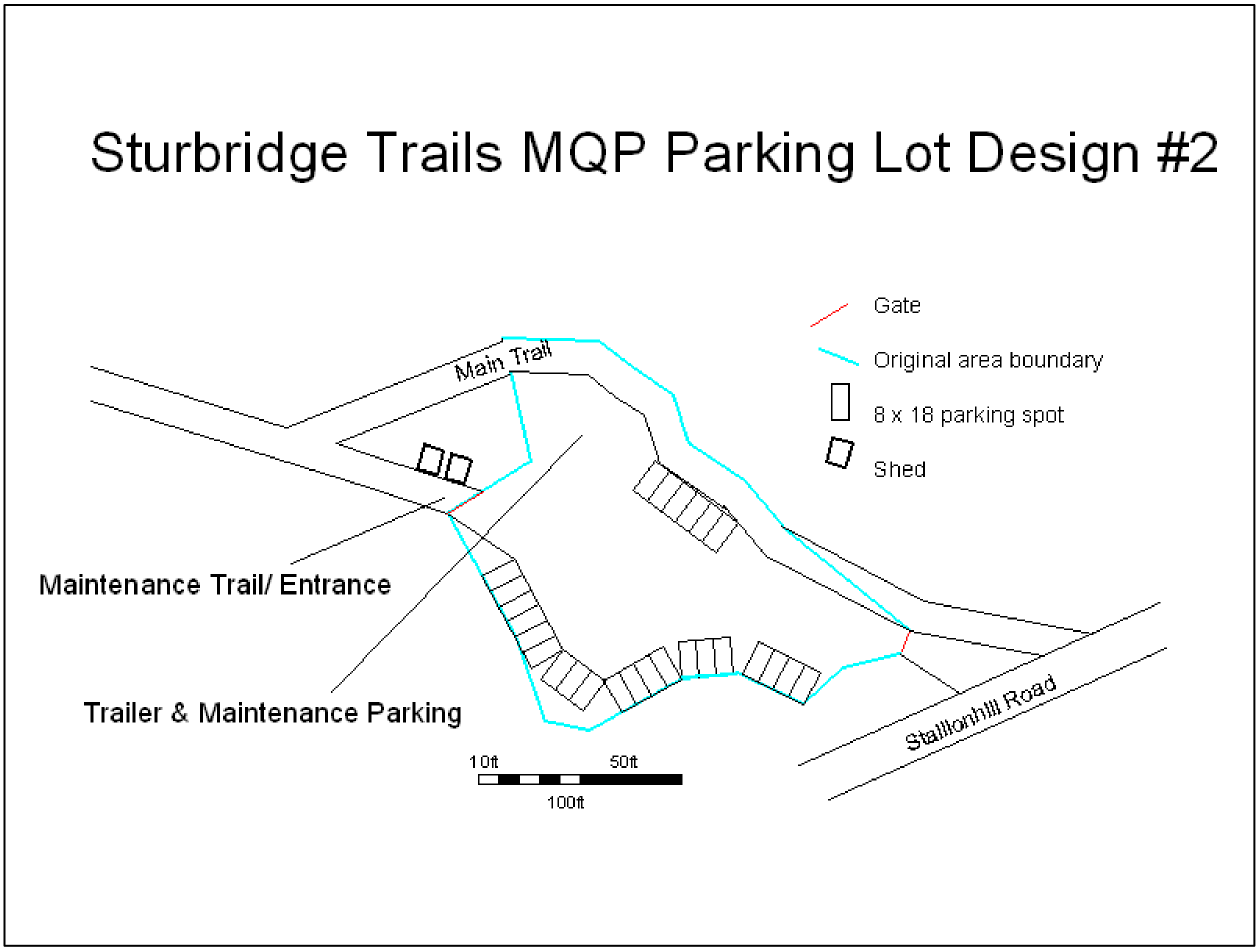

Figure 17: Preliminary Parking Area Design 2

Table 4 : Preliminary Parking Area Design Features

Requirement	Alternative #1	Alternative #2
Storage Shed Undisturbed	✓	
Light Pole Undisturbed		
Separate Walking Trail		✓
No Excavation	✓	
Maintenance Area	✓	✓
Trailer Turn-around	✓	✓
Parking Capacity	30	26

Feedback

At the January 13 meeting of the STC, the members of the Committee specified that the horse trailer parking should be as separate as possible from the main parking area to increase safety during the unloading, preparing, and loading of horses. Also, a radial turnaround area for trailers was deemed preferable to an area that would require trailers to back in or execute three-point turns. In order to accommodate these changes the Committee members suggested that the maintenance material storage area could be reduced in size and relocated further along the path of the trail, rather than adjacent to the parking area.

The Committee also requested that the parking area be in compliance with the Massachusetts River Protection Act, by remaining outside of a 200ft buffer area from the Quinebaug River if possible (Regulations for the Wetlands Protection Act, 87-90). Another request was to change the size of the parking spaces to 10ft by 20ft, which is the standard for the Town of Sturbridge. The preliminary designs featured 9ft wide and 18ft long parking spaces. Additionally, ADA-compliant spaces were to be included in the design revisions. The Committee requested that the existing 10-foot by 12-foot maintenance shed as well as the existing concrete foundation pilings for an expected second shed, measuring 8-feet by 16-feet, that are adjacent to the current shed, be left undisturbed. Preliminary Design 1 accounted for the existing maintenance shed, but not the location of the existing pilings for a new shed. Preliminary Design 2 required the relocation of both the existing shed and foundation pilings for the second to minimize the required excavation of the existing hillside to accommodate the walking trail. The STC decided that some hillside excavation would be acceptable in the design of the parking area, particularly if it was required in order to accommodate a trail entrance off of Stallion Hill Road apart from the parking area entrance.

Another specification from the Sturbridge Trails Committee was the incorporation of stormwater best management practices (BMPs) for the final parking area designs. These could be similar to stormwater management systems employed for other Sturbridge Trails projects that included unpaved parking areas. Plans from other STC projects were reviewed for information regarding previously used stormwater BMPs. From the information gathered through research and feedback from the Sturbridge Trails Committee, two final design alternatives for the trailhead parking area were created from the preliminary designs, incorporating the comments and suggestions gathered from the STC meeting on January 13, 2011. These two final design alternatives are detailed in the Results, Section 4.2.1.

3.5 Culvert Design

The methodology of the culvert design began with a preliminary evaluation, consisting of a hydrological analysis of the contributing watershed and calculation of the available storage on the site upstream of the culvert. This data was used in the design process for the hydraulic design and structural recommendations of the culvert alternatives. Two design alternatives were selected, a corrugated plastic pipe and a concrete box culvert. The following sections outline the process followed for the design of the culverts. The application and results of this process is located in the Results, Section 4.3.

3.5.1 Hydrological Analysis

A hydrological analysis of the Riverlands site was required prior to designing replacement alternatives for the washed-out culvert. This analysis determined the extent of the contributing watershed area as well as the volume and flow rate of runoff expected at the outlet point of the site, the location of the washed-out culvert. Two methods from the NRCS Technical Release 55 Manual (TR-55) were employed to determine the hydrologic design parameters for the project. The TR-55 Graphical Peak Discharge Method was used to determine the peak flow of stormwater runoff from the contributing watershed area to the culvert crossing. The TR-55 Tabular Hydrograph Method was used to create a hydrograph showing flow over time for the discharge of the watershed.

Estimating Runoff

The drainage area contributing to the outflow at the location of the washed-out culvert was determined using the method described in Introduction to Stormwater: Concept, Purpose, Design (Ferguson, Chapter 4). ESRI's ArcGIS software was used to visually delineate the watershed using this method and incorporated MassGIS 10ft elevation contours. The eastern border of the drainage area was chosen to coincide with the edge of the MassGIS drainage sub-basin line for the Quinebaug River watershed. The extent of the contributing watershed area can be seen in Figure 18. The total contributing watershed area was calculated to be 172 acres.

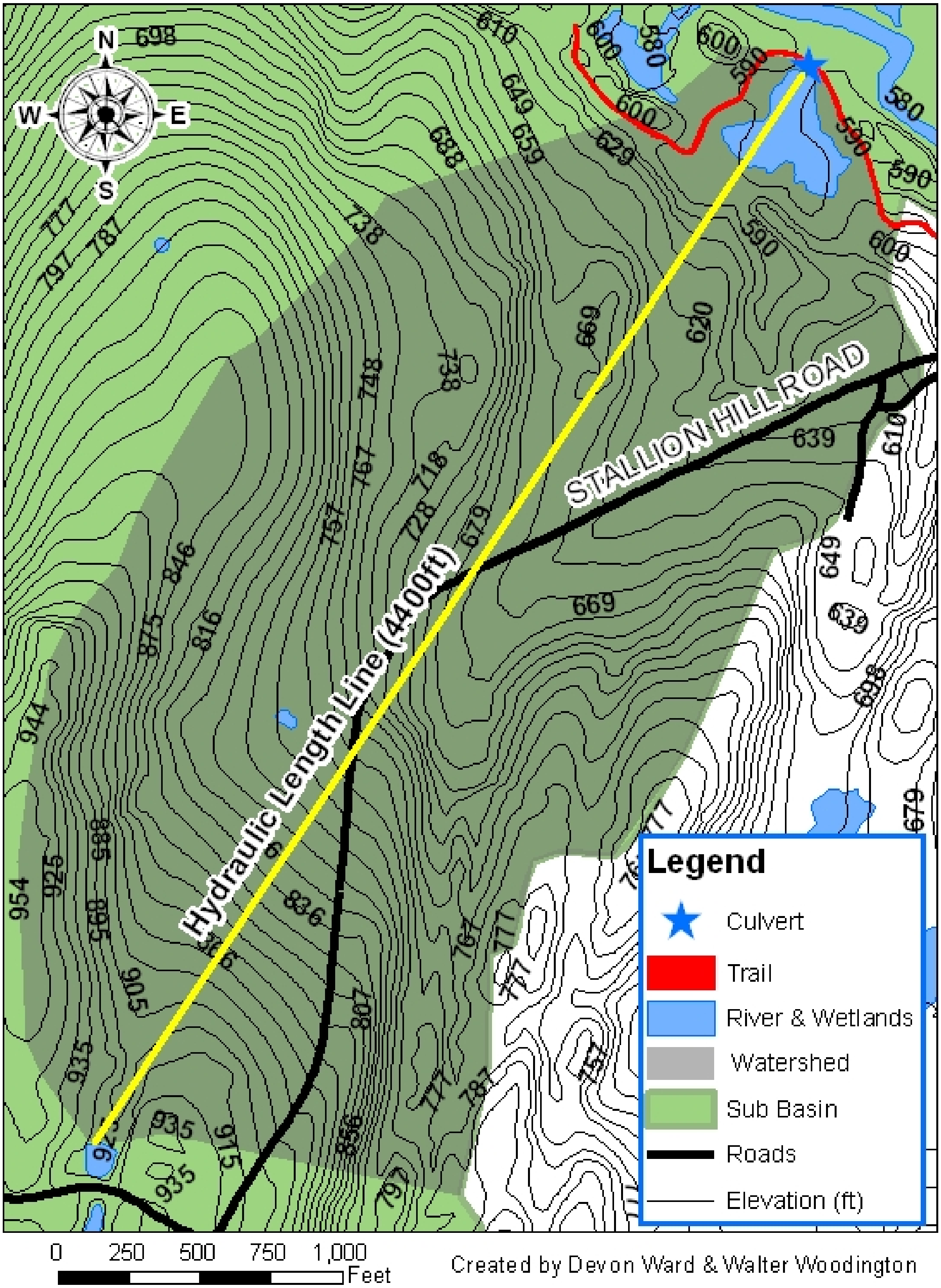

Figure 18: Contributing Watershed & Hydraulic Length

A 25-year design storm was used for the analysis, as specified by the Sturbridge Trails Committee (STC). The SCS runoff curve number method from TR-55 was used to determine the depth of runoff associated with the 25-year design storm for the area (NRCS, Chapter 2). The SCS Runoff Equation is shown below.

Equation 1: SCS Runoff Equation

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$

The amount of precipitation (P) was obtained for a typical 25-year rainfall event in the Massachusetts area (NRCS, Figure B-6). A value of five inches was used for the SCS runoff equation. The initial abstractions (Ia) were estimated using the empirical equation:

Equation 2: Approximating Initial Abstraction

$$\mathrm{Ia} = 0.2S$$

Where S is the potential maximum retention after runoff begins. The variable S is related to the SCS runoff curve number (CN) by the equation:

Equation 3: Relation of S to CN

$$S = \frac{1000}{CN} - 10$$

The selection of a CN value is based upon land use, soil type, and hydrological conditions for the contributing watershed. Land use information for the contributing area was obtained from the MassGIS data layer. The land use for the selected contributing watershed was predominantly woods. The soil type for the watershed was determined to be soil type C (NRCS, Exhibit A). Fair hydrological conditions were assumed for the contributing watershed. The land use and soil type information was combined to determine the SCS runoff curve number which was selected to be 73 (NRCS, Table 2-2c). Solving Equation 1 with the variables given in Table 5, the final runoff depth was calculated to be 2.3in as shown in Equation 4.

Table 5: SCS Runoff Equation Variables

Variable	Value
P (in)	5.00
Ia (in)	0.74
S (in)	3.70

Solving for runoff depth yielded:

$$Q = \frac{(5 - 0.74)^2}{(5 - 0.74) + 3.7} = 2.3in$$

Calculating Time of Travel

The hydraulic length (L) necessary for calculating the time of travel using the TR-55 method was obtained by drawing a straight line from the outlet point (culvert site) to the highest topographical point furthest away within the contributing drainage area. This length was found to be approximately 4,400ft and was used in equation 3-1 from TR-55. The value for time of concentration (T_c) was assumed to be equal to the time of travel (T_t) because there were no subdivisions to the contributing watershed used for analysis. Equation 4 shows the calculation used to determine time of concentration for the watershed:

Equation 4: Time of Concentration

$$T_C = \frac{L}{3600\,V}$$

The velocity (V) used for Equation 5 was determined using Manning's Equation for open-channel flow.

Equation 5: Manning's Equation

$$V = \frac{1.49 r^{2/3} s^{1/2}}{n}$$

As there is no clear open channel flow for a majority of the contributing watershed, a value of 0.4 was used for the hydraulic radius (r) for unpaved areas (NRCS, Appendix F). The slope (s) of the hydraulic length was calculated from the MassGIS contour lines using ArcGIS and was found to be 8.5%. The roughness coefficient (n) for Manning's Equation was determined to be 0.4 (NRCS, Table 3.1). Solving for velocity yielded:

$$\mathrm{V} = \frac{1.49(0.4)^{2/3}(0.085)^{1/2}}{0.4} = 0.77\ fps$$

The average velocity of flow was calculated to be 0.77fps. This value was then inserted into Equation 4 to obtain the time of concentration:

$$\mathrm{T_C} = \frac{4400\ \mathrm{ft}}{3600\ (0.77\ \mathrm{fps})} = 1.6\ hours$$

The total time of concentration was calculated to equal 1.6hrs.

Calculating Peak Flow at Culvert Crossing

The TR-55 Graphical Peak Discharge Method was used to calculate the peak flow of the watershed at the outlet point. The peak discharge equation, Equation 6, was used for the calculation:

Equation 6: The Peak Discharge Equation

$$\mathrm{q_p} = \mathrm{q_u A_m Q F_p}$$

The unit peak discharge (q_u) was found using Exhibit 4-III from TR-55. A_m is the contributing area in square miles, Q is the depth of runoff in inches, and F_p is the pond and swamp adjustment factor. While the contributing watershed contains wetlands, they are in the direct path of flow to the outlet and therefore the pond and swamp adjustment factor was not used. The obtained values were then substituted into Equation 6 to calculate the peak flow from the contributing watershed at the outlet point:

$$q_p = (220 csm/in)(0.269 mi^2)(2.3 in)(1) = 136\ cfs$$

The peak flow was calculated to be 136cfs.

Creating an Inflow Hydrograph

A hydrograph showing the expected flow at the culvert crossing versus time was needed in order to determine the required storage of stormwater based on the flow through the culvert. The Tabular Hydrograph method for estimating flow was used, as described in Chapter 5 of TR-55. Since there were no subdivisions of the contributing watershed, only one hydrograph was created. In order to select the appropriate values for the hydrograph, the ratio of Ia to P was calculated in Equation 7 as:

Equation 7: Ratio of Ia/P

$$\frac{Ia}{P} = \frac{0.74}{5.00} = 0.15$$

This value was rounded to the nearest table value, 0.10, in Exhibit 5-III of TR-55. The hydrograph produced can be seen in Figure 19.

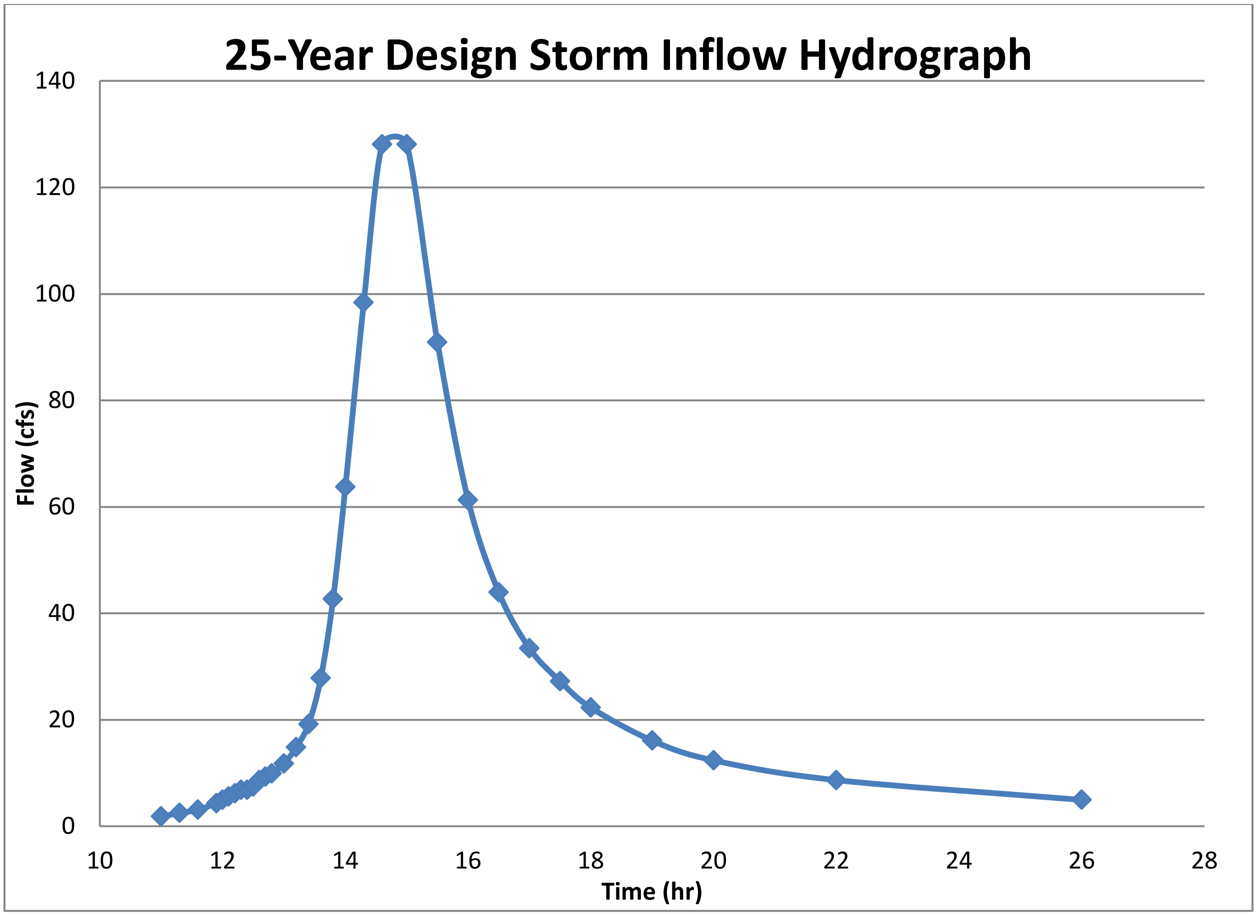

Figure 19: Inflow Hydrograph

Site Visit Flow Measurement

Table 6 presents the flow data that was collected during the site visit on November 17, 2010. The observations were recorded at 9:51am. The velocity of flow through the culvert crossing was measured at one foot intervals across the nine-foot diameter stream. Each measurement was recorded at the mean depth of flow for that segment. Using the estimated cross-sectional area and velocity, the individual segment flows were calculated then summed to find the total average flow through the culvert crossing.

Table 6: Flow Meter Observations

Observations recorded Nov. 17 2010 at 9:51am					
Section Number	Width (ft)	Depth (ft)	Velocity (ft/s)	Area (ft^2)	Flow (cfs)
1	1.00	0.40	1.30	0.20	0.26
2	1.00	0.70	1.60	0.55	0.88
3	1.00	1.10	2.10	0.90	1.89
4	1.00	1.30	1.90	1.20	2.28
5	1.00	1.40	2.40	1.35	3.24
6	1.00	1.00	2.60	1.20	3.12
7	1.00	1.00	1.60	1.00	1.60
8	1.00	0.55	0.40	0.78	0.31
9	1.00	0.00	0.40	0.28	0.11
				Total Flow (cfs) =	13.69

The total rainfall recorded for November 17, 2010, by the NOAA observation station at the Worcester Regional Airport totaled 1.4 inches (NOAA-1). 24-hour duration was assumed for this rainfall total, and the rainfall event frequency for a storm with this precipitation was determined to be less than a 2-year storm by using an Intensity-Duration-Frequency (IDF) curve for the Worcester area (MassDot-2, Exhibit 8-14). If a storm with less than a 2-year return period produced a flow of approximately 14cfs through the culvert crossing, then 136cfs calculated peak flow for a 25-year return period storm is a reasonable design parameter because it represents an appropriate scale increase in flow from the 2-year to 25-year storm.

3.5.2 Available Storage Calculation

Available storage is the amount of water that can pool upstream of the culvert without overtopping it. The storage area for this site consists primarily of wetlands and forest. The height of available storage behind the culvert is based on the geometry of the culvert crossing. This height is the distance from the stream bed to the finished surface of the trail and was conservatively measured during a site visit to be approximately six feet. This value was reduced to five feet for design calculations to prevent overtopping and to ensure that the design was conservative. The available storage surface area of the site was determined using MassGIS ten-foot contour lines and wetlands layers. The area encompassed was found to be 137,700ft^2 and can be seen in Figure 20. This value was multiplied by the height of five feet to find the total available storage volume which was calculated to be 688,500ft^3.

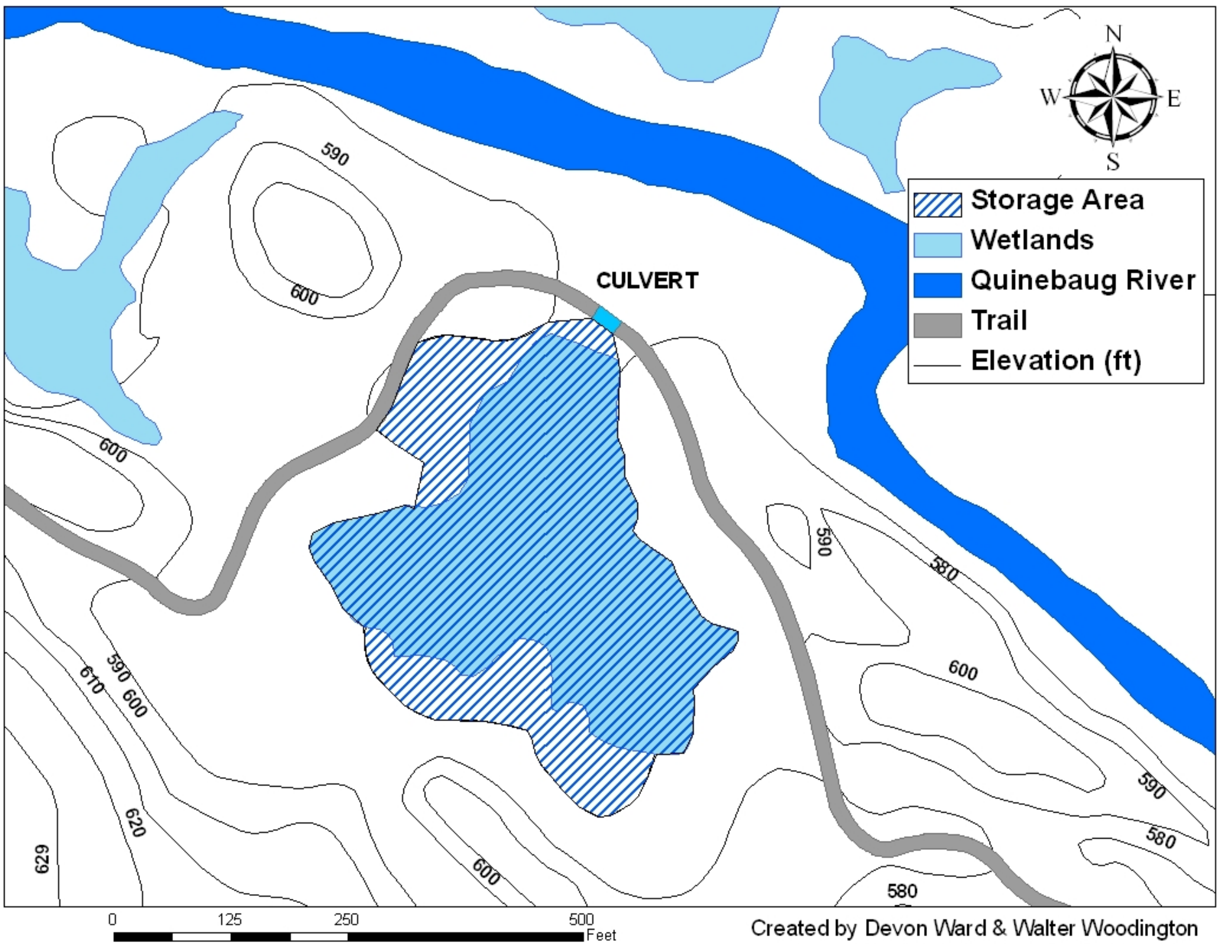

Figure 20: Map of available storage area

3.5.3 Culvert Design Requirements

Design requirements for the culvert came from multiple sources and affect five components of the design. Geometric constraints were measured during the site visits. The height of the trail surface from the stream bed and the width of the stream bed determined the maximum size of the culvert that could fit on the site. The topography of the region upstream of the culvert was used to calculate the available stormwater storage of the culvert inlet. The hydrological calculations yielded an outflow hydrograph. From this hydrograph the peak flow was used to size the culvert. Correspondence and meetings with The Sturbridge Trails Committee about expected types of uses and vehicular traffic on the trail was used to define a maximum live load on the culvert. These requirements are summarized in Table 7.

Table 7: Culvert Design Requirements and Sources

Design Area	Source	Requirement
Topography	MassGIS Contours	Available Storage Volume = $137{,}700ft^2 \times 5ft = 688{,}500ft^3$
Design Storm	Sturbridge Trails Committee Meetings	Culvert should handle peak flows for a 25-year rain event.
Hydrology	Hydrological Analysis	Contributing Watershed Hydrograph Peak Culvert Inflow = 136cfs
Max Live Loads	Sturbridge Trails Committee Meetings	Logging trucks should be accommodated. Highway 20 Rating
Geometry	Site Visits	Streambed to Trail Height = 6ft

3.5.4 Culvert Design Process

The culvert was designed to handle the outflow from the hydrological calculation, the peak flow being 136cfs as calculated in Section 3.5.1. It also was designed to withstand the dead load of the soil and the live load of logging trucks while fitting within the geometric constraints of the site.

First the culvert was sized to the maximum geometry that would fit on the site. Then hydraulic calculations were performed using the culvert geometry to determine the maximum outflow that the culvert could handle. The outflow from the hydraulic calculations was compared to the flow levels predicted by the inflow hydrograph and the maximum required storage was calculated using this information. Storage would be required when the inflow to the culvert exceeded the maximum outflow of the culvert, resulting in a volume of water pooling upstream of the culvert. The available storage was calculated using the site topology and found to be approximately 688,500ft^3. If the maximum required storage was less than or equal to the available storage then the design was adequate. However, if it was greater than the available storage, then the culvert was resized and the design calculations were repeated.

3.5.5 Culvert Alternatives

Two culvert design alternatives were created. The first was a corrugated plastic pipe culvert, and the second was a concrete box culvert. These two alternatives were selected based on recommendations from the Sturbridge Trails Committee and a consulting engineer hired by the STC. It is expected that an engineering firm will finish the design and site development work on this site for the Town of Sturbridge.

The Trails Committee and the Sturbridge Conservation Commission expressed a desire for an open bottom or at the least a natural bottom so that the culvert does not interfere with the organisms that inhabit the stream bed and surrounding area. For this reason a concrete box culvert was selected which would be able to carry large loads and has an open bottom. A corrugated plastic pipe was selected as an alternative because it is simple to install and relatively inexpensive. The STC wanted an inexpensive and simple option, and their consultant recommended a pipe culvert based on their prior experience with this type of installation. A layer of soil fill was designed in the pipe to simulate a natural bottom which was used to satisfy the design requirement of the Sturbridge Conservation Commission of a natural bottom.

In order to design the corrugated plastic pipe culvert the design guides provided by pipe manufacture, Advanced Drainage Systems, were used (ADS). Specific design guides for pipe property information and the structural design recommendations can be found on the company website. The MassDOT's 2005 Bridge Manual was used to design the concrete box culvert (MassDot-1).

3.5.6 Pipe Culvert

To start the design process a preliminary pipe size was selected for the hydraulic and structural analysis. A nominal corrugated plastic pipe size of 4 feet was selected from the ADS website. That size was selected because it would fit in the constraints of the site geometry and provide a large amount (three feet) of cover for the structural integrity. The culvert was designed using an ADS Dual Wall N-12 High Performance Storm pipe which comes in nominal sizes ranging from 12 to 60 inches (ADS).

Hydraulic Calculations for Outflow of Pipe Culvert

It was assumed that Inflow controls the flow through the pipe because the outflow can flow unrestricted from the culvert outlet into the Quinebaug River and a large area of water storage is provided at the culvert's inlet. Two methods were selected to account for two different flow limiting cases. The more conservative of the options was used to calculate the required storage.

Method One: Orifice Flow

The entrance of the pipe was assumed to limit outflow of the pipe. The orifice flow equation, shown in Equation 8, was used to determine the peak outflow at maximum storage (Sturm, Equation 6.11).

Equation 8: Orifice Flow Equation

$$\boldsymbol{Q = C_d A_c \sqrt{2g(HW)}}$$

$$Where\ Q = Flow\ (cfs)$$

$$C_d = \frac{1}{\sqrt{1+K_e}} = Coefficent\ of\ Discaharge\ (Unitless)$$

$$A_c = 8.38\ ft^2 = Cross\ Sectional\ Area\ of\ Culvert\ (ft^2)$$

$$g = 32.2\ \frac{ft}{s^2} = Accelertation\ of\ Gravity\ (\frac{ft}{s^2})$$

$$HW = 5\ ft = Head\ Water\ (ft)$$

$$K_e = 0.9\ = Entrace\ Loss\ Coefficent$$

The cross sectional area of the culvert was calculated assuming one foot of sediment fill inside the culvert pipe to simulate a natural bottom. The headwater depth was assumed to be five feet at the maximum storage case based on site topology. The entrance loss coefficient is from plastic pipe manufacturer ADS's Drainage Handbook. Substitution of variables yields:

$$C_d = \frac{1}{\sqrt{1+K_e}} = \frac{1}{\sqrt{1+0.9}} = 0.7255$$

and

$$Q = C_d A_c \sqrt{2g(HW)} = (0.7255)(8.38)\sqrt{2(32.2)(5)} = \boldsymbol{109.1\ cfs}$$

This resulting outflow is 109.1cfs.

Method Two: Conservation of Energy

Assuming that the pipe and fill roughness will limit the outflow, an equation based on the conservation of energy was used to calculate the flow capacity of the culvert designs. The head loss in the pipe is shown in Equation 9 (Houghtalen, Equation 8.18).

Equation 9: Headloss Equation

$$\boldsymbol{h_L = \left(K_e + \frac{n^2 L}{R_h^{4/3}} + 1\right)\frac{8Q^2}{\pi^2 g D^4} = Head\ loss}$$

The entrance loss coefficient K_e was found to be 0.9 (ADS, Table 3-3).

The Manning's n value is used to account for the energy lost from the flowing water in contact with surfaces of varying roughness as well as the contours and winds of the channel. A larger value means the material is rougher and/or in a more winding channel, and therefore will more greatly decrease the energy of the water and, in turn, decrease the velocity of the flow. For the pipe culvert the flowing water will be in contact with the soil fill and the walls of the pipe. The pipe is straight so Manning's n will be mostly affected by the roughness of the materials. The Manning's n for soil was selected as 0.03 (Sturm, Table 4-1). The Manning's n for the ADS pipe was selected as 0.0012 (ADS, Table 3-1).

A composite Manning's n value was calculated to account for the differing Manning's n values of the soil and the pipe wall materials and their differing contact patches with the full-flowing pipe. This was done by calculating the portion of the wetted perimeter that was comprised of soil and the portion comprised of the plastic pipe. By multiplying each by their respective Manning's n values, and then dividing the weighted n-value by the total wetted perimeter, the composite Manning's n value was calculated. This calculation is shown in Equation 10.

Equation 10: Composite Manning's n Calculation

$$n = \frac{(Soil\ Contact = 3.46\ ft)(soil\ n = 0.03) * (Pipe\ Contact = 8.34\ ft)(Pipe\ n = 0.0012)}{(Soil\ Contact = 3.46ft) + (Pipe\ Contact = 8.34ft)}$$

$$Composite\ Manning's\ n = 0.0173$$

$$L = 20\ ft = Culvert\ Length\ (ft)$$

$$R_h = \frac{Cross\ Sectional\ Area}{Wetted\ perimeter} = \frac{8.38}{11.84} = 0.707\ ft$$

$$Q = Flow\ (cfs)$$

$$g = 32.2\ \frac{ft}{s^2} = Accelertation\ of\ Gravity\ (\frac{ft}{s^2})$$

$$D = 4\ ft = Culvert\ Diameter\ (ft)$$

The energy balance for this culvert is show in Equation 11:

Equation 11: Pipe Culvert Energy Balance

$$HW + S * L = D_e + h_L$$

$$HW = 5\ ft = Head\ Water\ (ft)$$

The headwater depth was assumed to be five feet at the maximum storage case based on site topology.

$$S = 0 = Slope\ (\frac{ft}{ft})$$

The culvert was designed for a zero slope case to be conservative; however, it is likely that the culvert will be constructed with a slight slope which would improve hydraulic performance by increasing flow.

$$L = 20\ ft = Culvert\ Length\ (ft)$$

$$D_e = 3\,ft = 4\,ft - 1\,ft = Effective\ Culvert\ Diameter\ (ft)$$

In this case the culvert was assumed to be embedded into the soil by one foot to maintain a natural bottom so the nominal four foot diameter pipe has an effective internal diameter of three feet. The head loss equation is substituted into the energy balance equation and solved for flow, resulting in Equation 12.

Equation 12: Energy Balance Equation

$$Q = \sqrt{\frac{HW + S * L - D}{\left(K_e + \frac{n^2 L}{R_h^{4/3}} + 1\right)\frac{8}{\pi^2 g D^4}}} = \sqrt{\frac{5 + 0 * 20 - 3}{\left(0.9 + \frac{0.0173^2 * 20}{0.707^{4/3}} + 1\right)\frac{8}{\pi^2 (32.2)(4)^4}}} = \mathbf{96.76\ cfs}$$

This resulting outflow is 96.7cfs. This is more conservative than using the first method and for that reason was selected as the design value to calculate storage.

Calculating Storage

The resulting outflow of 96.7cfs from method two, conservation of energy was overlaid onto the hydrograph shown in Figure 19 to create the resulting inflow-outflow hydrograph seen in Figure 21. This figure was used to calculate the required storage. This required storage of 86,800ft^3 is less than the available storage, 688,500ft^3 so the design was deemed adequate. In other words a 25-year rain event is not expected to overtop the trail at the culvert inlet.

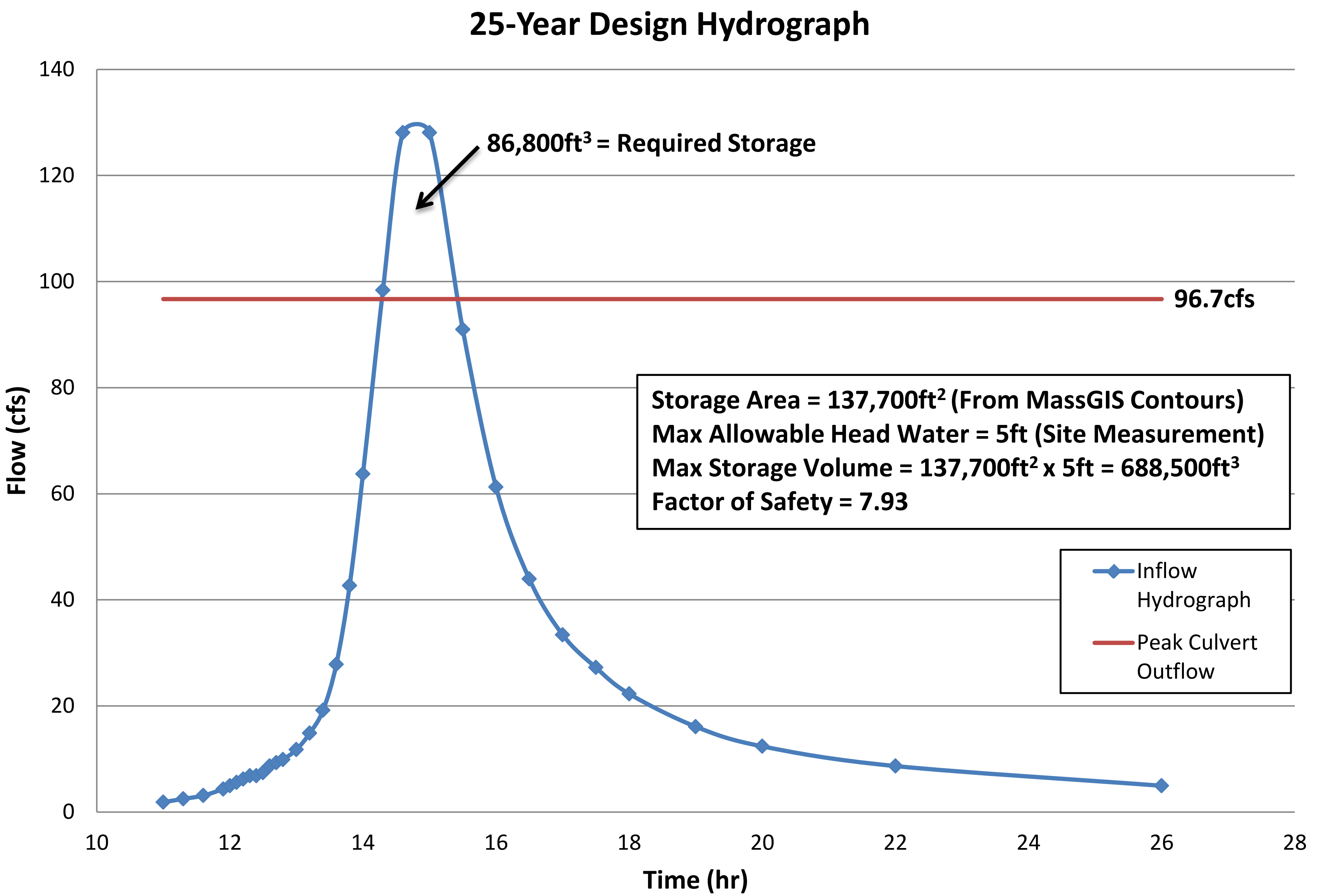

Figure 21: Inflow/Outflow Hydrograph showing Wetland Storage

Structural Considerations for Pipe Culvert

The pipe culvert was first sized for hydraulic considerations which fit within certain geometric constraints determined by the trail and site geometry. Using these constraints and pipe characteristics proper installation conditions were determined using the manufacturer's guide, The ADS Drainage Handbook.

Design Loading

The Sturbridge Trails Committee identified an AASHTO H-20 load as the target live load capacity. An H-20 rated truck means that its expected maximum axle live load is 32 tons (ADS Figure 2-1). This H-20 rating is requested by the Committee to ensure that further clearing and development of the site will be possible, which may require heavy equipment and logging trucks.

The culvert must also carry a dead load from the overlying soil and pavers. These loads are expected to be much less than that of the vehicle live load from logging trucks. The types of existing soil and cover materials are unknown.

Cover Depth

The depth of soil cover over the pipe culvert was determined using simple geometry. The distance from the stream bed to existing trail is approximately six feet. The pipe is four feet in diameter but is submerged one foot into the soil to mimic a natural bottom for wildlife. This leaves three feet of soil between the top of the culvert and the trail bed.

Determining Allowable Loading

For permanent installations with vehicle traffic, without pavement such as a gravel driveway The ADS Drainage Handbook recommends “a total minimum cover of 18-inches (0.5m) for 4- to 48-inch (100-1200mm) diameters and 30-inches (0.8m) for 54- and 60-inch (1350mm and 1500mm) diameters is recommended to minimize rutting” (ADS, 5-13). This case is similar to the trail characteristics so a minimum cover of 18in is required.

During construction the ADS Drainage Handbook recommends three feet of cover to carry loads between 30 and 60 tons for temporary loading situations (ADS, 5-20). The three feet of cover that will fit the geometry of the site is also adequate for loads of 30 tons during construction and assumed higher loads once the fill is properly graded and the culvert construction completed (ADS, 5-13). For this reason three feet of cover is recommended for the culvert installation.

3.5.7 Box Culvert

Precast Concrete Three-Sided Culverts have a maximum span of approximately 40ft (MassDOT-1, 2.3.3.1). These units are supported on strip footings founded on gravel, rock, or piles. However, due to their fixed span to depth ratios, it may be difficult to ship the larger size units to the construction site. In areas of high fill (more than 16ft) there may be design problems with flat top units with long spans. Skewed arrangements must be considered in design as not all manufacturers produce units with skewed end walls. The design should be coordinated with the appropriate manufacturers.

Hydraulic Calculations for Box Culvert

The construction of a box culvert involves significantly more site work than that of a pipe culvert. The small size of the site means that the cost to construct a box culvert designed to meet the flow requirements would be approximately the same as that for an overdesigned one. For this reason the culvert was overdesigned to not require storage, while passing the peak flow from the inflow hydrograph in Figure 19.

In order for the box culvert to not require storage the outflow from the culvert must be equal to or greater than the peak inflow to the culvert. To ensure the design was capable of passing the required outflow, without overtopping the trail, the associated head water was calculated and compared against the allowable headwater from site geometry. An equation to calculate the expected headwater at peak flow from the book Open Channel Hydraulics by Terry Sturm was modified so it could be solved with known data. The head loss due to friction was rewritten in terms of Manning's equation instead of the Darcy-Weisbach equation. This modified equation can be seen in Equation 13 (Sturm, 224).

Equation 13: Modified Energy Equation

$$HW\ (Head\ Water) = TW - SL + \left(1 + K_e + \frac{2gn^2L}{1.49^2 R^{4/3}}\right) < HW_{Allowable}$$

To begin the hydraulic analysis of the box culvert, the variables in the modified energy equation were determined. These variables, their meanings, and values can be seen in Table 8. Next, preliminary internal dimensions of three feet high and four feet wide for the box culvert were set. The last step was to compare the resulting headwater from the modified equation to the allowable headwater. If the resulting headwater was less than or equal to the allowable headwater then the design was adequate to prevent overtopping. If the resulting headwater exceeded the allowable storage, then the design was inadequate and the culvert geometry was redesigned and headwater recalculated. The calculations preformed were computed by hand and using Microsoft Excel.

Table 8: Input Variables for Modified Energy Equation

Variable	Meaning	Value
TW	Tailwater	0ft
S	Slope	0ft/ft
L	Length	52ft
Ke	Entrance Headloss Coefficient	0.5
g	Acceleration of Gravity (Constant)	$32.2 ft/s^2$
n	Manning's n	0.02143
R	Hydraulic Radius	$1.167 ft^{-1}$
$HW_{allowable}$	Allowable Headwater	5ft

Tail Water is the height of water relative to outlet invert. In this case the water is free flowing out of the culvert into the Quinebaug River. Therefore no water builds up downstream, meaning there is no tail water. Slope is measured along the length of the culvert. A positive slope will decrease flow and a negative slope will increase flow. In this case there will be no designed slope.

The length of the culvert affects the effect of slope and the material properties on flow. The length of the culvert must account for the width of the trail, width of the shoulder and material supporting the trail. The width of the finished trail including shoulders is 16ft. The length of the supporting material was determined by the height of the trail and side slope of the supporting material on both sides. The height of the trail from the culvert invert was estimated to be six feet. The slope of the supporting material was designed to be 3:1 and must be accounted for twice. This calculation can be seen in Equation 14.

Equation 14: Box Culvert Length Calculation

$$L = Length = Trail\ Width + 2 * Material\ Slope * Height\ = 16 + 2 * 3 * 6 = 52\ feet$$

The entrance head loss coefficient accounts for energy losses caused by the shape and characteristics of the entrance to the culvert. In this case the box culvert was assumed to be simple, without wingwalls or other inlet features. Using this information the value for the entrance head loss coefficient was selected to be 0.5 (Sturm, Table 6-5).

The Manning's n value is used to account for the energy lost from the flowing water in contact with surfaces of varying roughness as well as the contours and winds of the channel. A larger value means the material is rougher and/or in a more winding channel and therefore will more greatly decrease the energy of the water and the velocity of the flow. For the box culvert the flowing water will be in contact with the soil of the streambed and the concrete walls of the culvert. The culvert is straight so Manning's n will be only be affected by the roughness of the materials. The Manning's n for soil was used as 0.03 (Sturm, Table 4-1). The Manning's n for the concrete, assumed to be rough, was 0.018 (Sturm, Table 6-3).

A composite Manning's n value was created to account for the differing Manning's n values of the soil and the concrete box walls as well as the differing contact patches between the water and the soil and, the water and the concrete box. This was done by calculating the contact patch of the soil and that of the concrete box and then multiplying each by their respective Manning's n values and dividing by the total contact area.

$$n = \frac{(Soil\ Contact = 4\ ft)(soil\ n = 0.03) * (Box\ Contact = 10\ ft)(Concrete\ n = 0.018)}{(Total\ Wetted\ Internal\ Perimeter = 14\ ft)}$$

$$Composite\ Manning's\ n = 0.02143$$

The hydraulic radius was determined by the extent of the flow and the culvert box dimensions. The culvert was assumed to be flowing full so the wetted internal surface area is the total inner surface area, 14ft.

$$R = \frac{Wetted\ Perimeter}{Area} = \frac{14}{12} = 1.167ft^{-1}$$

Using the values from Table 8, the modified energy equation was solved and checked against the allowable headwater. This equation was satisfied and the preliminary internal dimensions of three feet high and four feet wide were determined to be adequate to prevent overtopping. The solved solution can be seen in Equation 15.

Equation 15: Modified Energy Equation Solved

$$HW = 0 - 0 * 52 + \left(1 + 0.5 + \frac{2 * 32.2 * 0.02143 * 52}{1.49^2 1.167^{4/3}}\right) = 4.11\ ft < HW_{Allowable} = 5ft$$

Structural Considerations for Box Culvert

The box culvert was first sized for hydraulic considerations which fit within the geometric constraints determined by the trail and site geometry. The design work for the concrete box culvert ended at this step because it was discouraged by the Sturbridge Trails Committee and their consulting engineer early on in the design process.

However if the design process had continued, the forces on the culvert would have been determined and the properties of the materials from which it would be constructed would be analyzed. Next, preliminary geometry of the culvert concrete and foundation footings would have been defined based on the required internal dimensions determined by the hydraulic analysis. The sides and top of the culvert would be designed separately. Then the forces would be applied to the preliminary geometry of the sides and top separately so that the concrete cross section and reinforcing could be designed. Finally the sides and top would be loaded and the forces would be checked against allowable forces determined by the material properties.

The culvert should be designed using the Load and Resistance Factor Design (LRFD) portion of the MassDOT 2005 Bridge Manual to be consistent with construction practices in the state. The forces on the culvert account for live loads, dead loads, and lateral loads. The design live load was a requirement from the Sturbridge Trails Committee that the culvert must have capacity for an AASHTO H-20 loading. As an additional factor of safety and to meet MassDOT requirements, it is recommended that culvert have capacity for an AASHTO H-25 loading. The design dead loads come from the self-weight of the concrete culvert and the weight of soil, fill, and trail finishing materials above the culvert. The design lateral loads come from the soil and water pressure on the sides of the culvert structure and would be calculated using equations from a soil mechanics text book.

The top of the culvert would be designed as a simply supported beam to resist the live and dead loads. Reinforcing and concrete would be designed to resist sheer stresses and bending moments. Then the sides of the culvert and their footings would be designed as retaining walls to resist the overturning moment caused by the lateral load and axial loads transferred from the top of the culvert. The sides of the culvert would also have to be designed as columns to resist the axial loads transferred from the top of the culvert. Buckling must also be taken in to consideration.

4 Results

The following section contains the summation of the work performed for this project. It is broken down into the three main portions of the project; trail design, parking area design, and culvert design. Each section presents all final diagrams and descriptions of the designs created, and cost estimations for each. Additionally, the alternatives for the parking area and culvert designs are explained in detail to highlight their differences.

4.1 Trail Design

The final designs for the length of recreational trail on the Riverlands site are presented in this section. The trail was designed to be in compliance with the Americans with Disabilities Act (ADA), the Massachusetts Wetlands Protection Act, Massachusetts River Protection Act, and the specifications of the Sturbridge Trails Committee (STC). Additionally, the design was created to meet the standards for the Titanic Rail Trail, which the trail length designed in this project will eventually become a part of. A cross section of the trail surface, required excavation and fills, and the materials to be used are presented. Solutions to stormwater and erosion controls are also addressed and are detailed in the following sections. The last portion of this section outlines the cost estimation for the construction materials required for the trail.

4.1.1 Trail Layout

A total trail length of approximately 2,780ft was designed for this project. This length begins at the trailhead entrance at Stallion Hill Road and follows the path of existing trail originally shown to the project group by the project contacts during the first site visit on

September 8, 2010. The path of the trail follows the Quinebaug River in a north-westerly direction, crossing the natural gas pipeline and high-tension power lines on the site, and ending at the top of the gravel pit face where the trail rejoins the original Grand Trunk rail bed grade. Figure 22 shows the final design layout of the trail surface in relation to Stallion Hill Road, the Quinebaug River, and the wetlands on the site. The trail detail shown is divided into the five sections created based on the categorized issues, as described in the Methodology, Section 3.3.2.

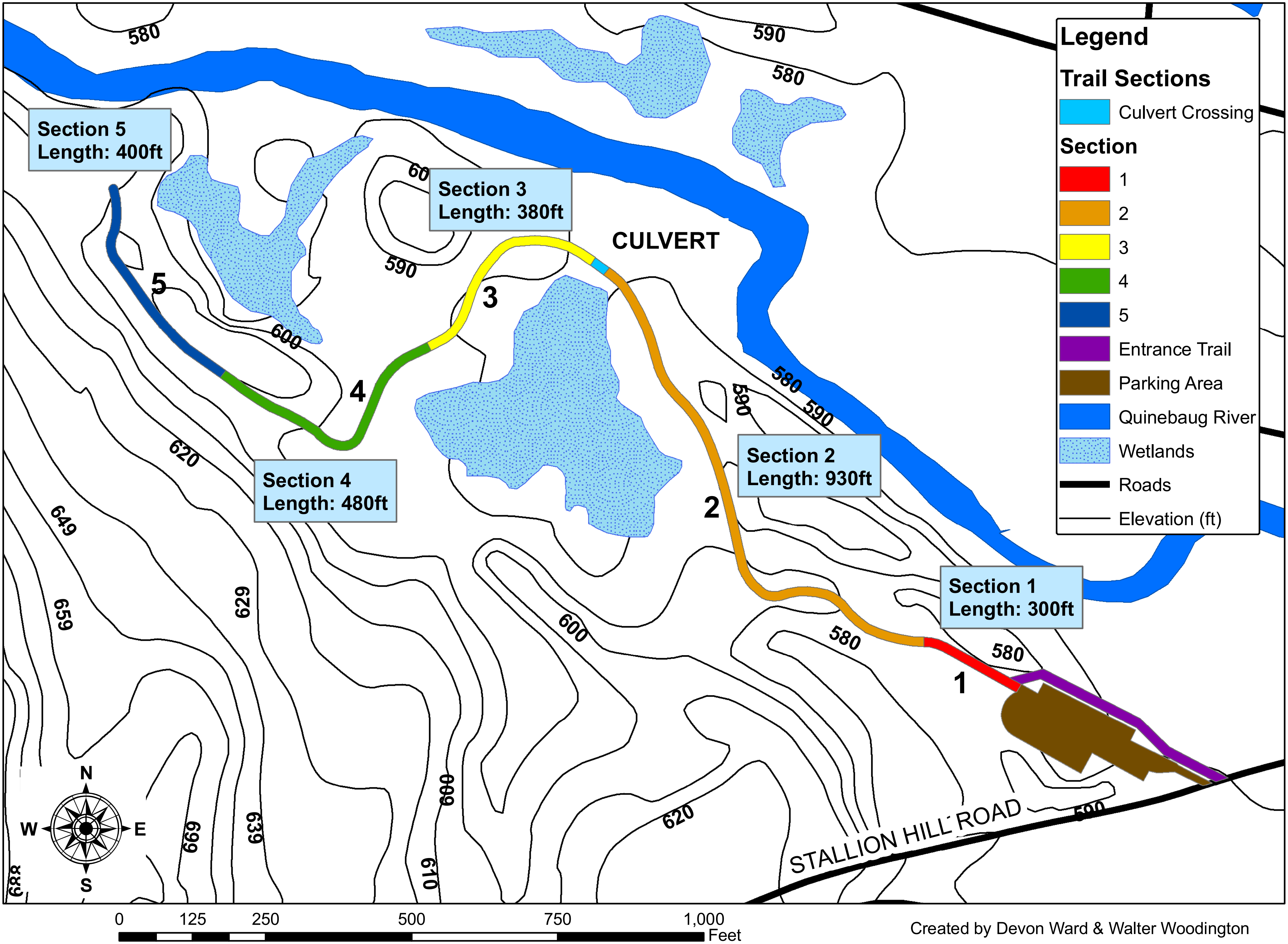

Figure 22: Trail Layout

4.1.2 Required Trail Work

The trail must be cleared, graded, and surfaced to meet the design requirements before it will be useable and compliant. The clearing dimensions account for all expected traffic on the trail. The gradation design meets the requirements of the ADA, and the trail surface meets the Titanic Rail Trail standards. The results of these three design areas are presented in this section.

Clearing

Brush and low hanging branches can be dangerous to bicycle and equestrian traffic on the trail. To create a safe travel corridor, minimum clearing distances on both sides of the trail as well as above the trail were set. The clearing recommendations are show in Table 9. Trail clearing width matches the Titanic Rail Trail standard of a continuous four-foot and continuous two-foot shoulder on either side of the finished trail surface. The clearing height above the trail should be able to accommodate pedestrians, cyclists, equestrians, and also maintenance vehicles. The Federal Highway Administration (FHWA) Equestrian Design Guidebook for Trails, Trailheads and Campgrounds recommends a 10 to 12 foot overhead clearance for a highly developed trail. The clearing is necessary for the entire length of trail.

Table 9: Trail Clearing Recommendations

Corridor Width	16ft
Overhead Height	12ft

Grading

To meet the requirements of the ADA the trail was designed to have a maximum grade of five percent (ADA, Section 4.3, Section 4.8). To accomplish this excavation and fill are required. Data from the site survey was used to create a plot of localized trail slope and trail elevation to identify segments of the trail above a five percent grade. The excavation and fill volumes were designed to be approximately equal to minimize the need for storage or import of soil fill. The trail layout showing areas of excavation and fill can be seen in Figure 23. The corresponding elevation model of the trail can be seen in Figure 24.

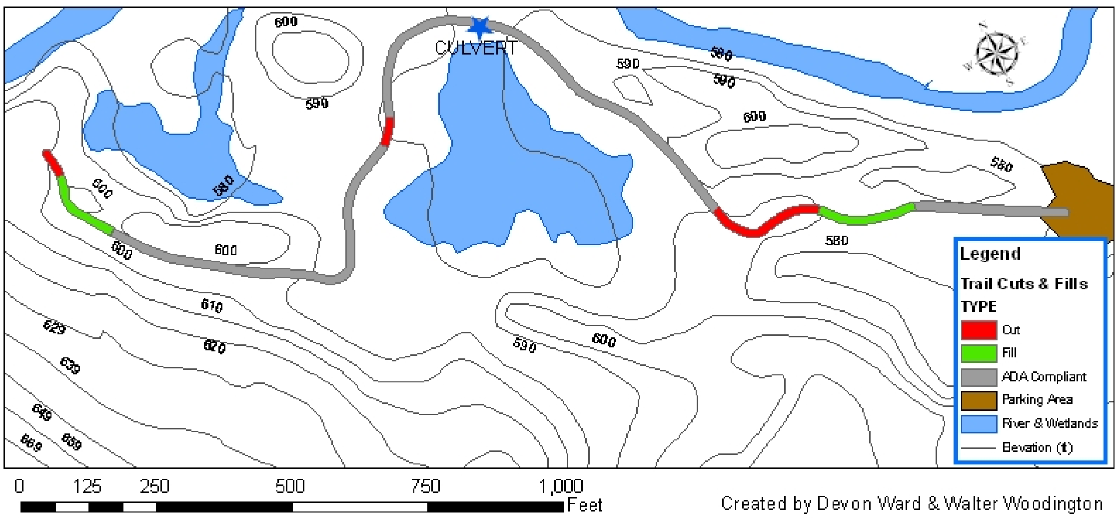

Figure 23: Excavation and Fill Location Map

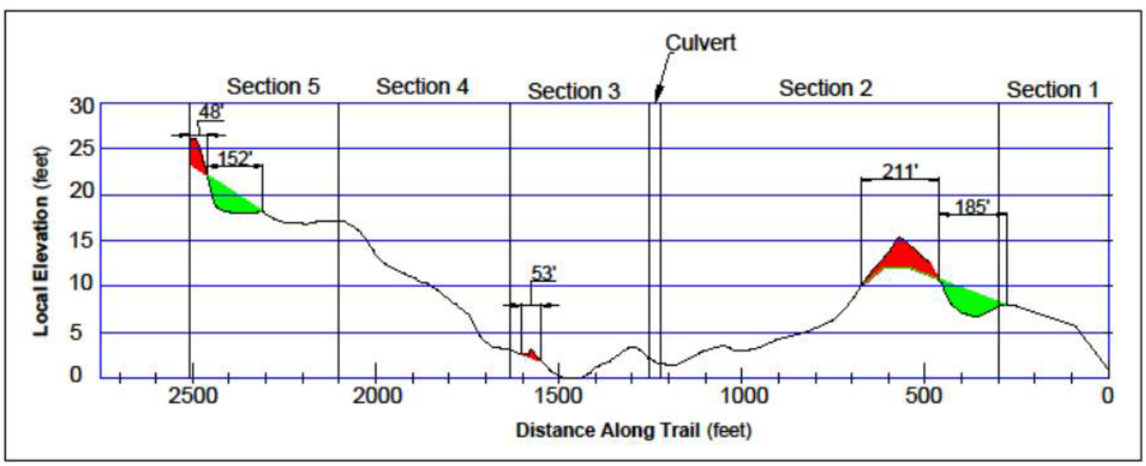

Figure 24: Elevation Model Showing Excavation and Fill

Surfacing

Trail width and surface were designed to meet the Titanic Rail Trail standard for continuity once the adjoining sections of the rail trail have been completed. After the grading and clearing have been completed, the trail will be surfaced on grade with four inches of packed half-inch-minus gravel. This is gravel that comes from crushed stone and includes all sizes below half an inch. The trail will be ten feet wide with a two-foot and four-foot shoulder composed of onsite loam. A cross section of the trail can be seen in Figure 25.

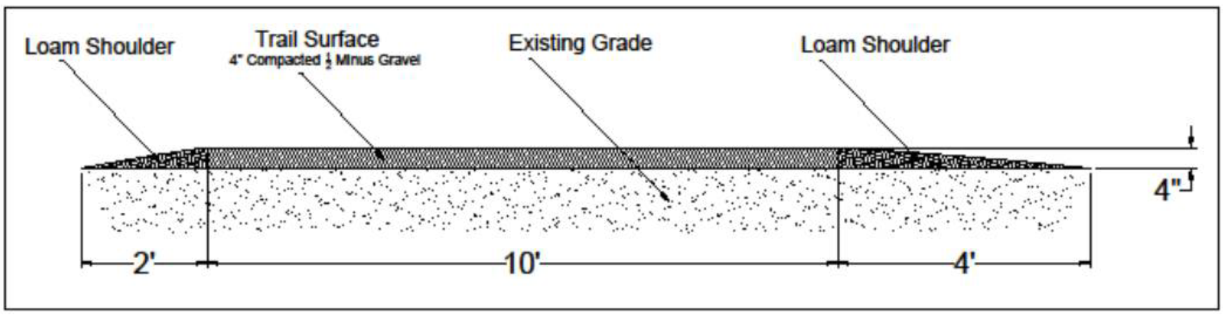

Figure 25: Trail Cross Section

4.1.3 Stormwater Best Management Practices

Grade dips were selected from the trail stormwater management methods that were researched. This method was selected because it is easy to maintain and would accommodate wheel traffic as well as horse and pedestrian traffic. Grade dips will be located in section four of the trail which was observed to have stormwater scarring and erosion. The layout of the trail and section numbers can be seen in Figure 22.

The dimensions of the grade dips were modeled after the recommendation in the Pitkin County, Colorado's <u>Trails Design and Management Hand Book</u> (Scott, 34). Different grades produce varying flow velocities and volumes, therefore the recommended grade dip dimensions vary when used on the areas of zero percent to five percent grade found on the trail. The cross section of a grade dip can be seen in Figure 26, and the corresponding dimensions for trail grades up to five percent can be seen in Table 10.

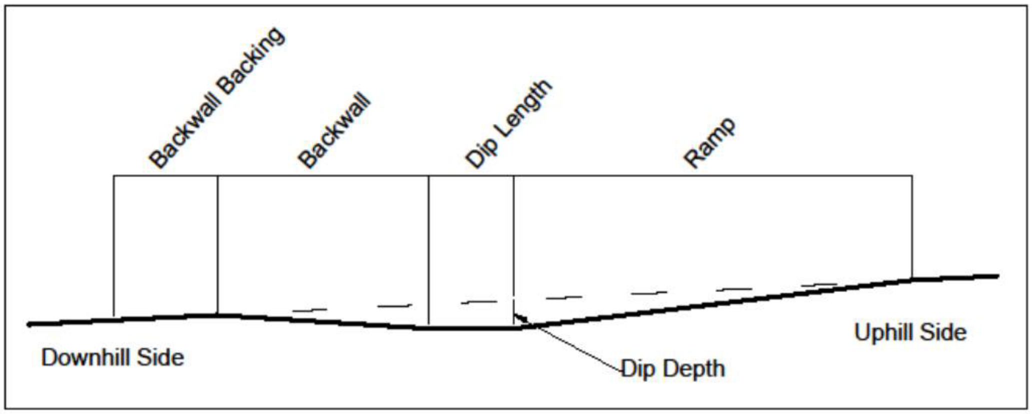

Figure 26: Grade Dip Cross Section

Table 10: Grade Dip Dimensions for Trail Grades up to 5%

Downhill Side

Trail Grade	Backwall Backing Length	Backwall Length	Dip Depth	Dip Length	Ramp Length
0%	0"	5'4"	3"	1'6"	5'4"
1%	4"	5'2"	3"	1'6"	6'5"
2%	8"	5'0"	3"	1'6"	7'6"
3%	12"	4'11"	4"	1'6"	8'6"
4%	1'4"	4'8"	4"	1'6"	9'7"
5%	1'8"	4'6"	4"	1'6"	10'8"

Uphill Side

4.1.4 Cost Estimation

The total length of the designed trail (including the length of proposed trail from Stallion Hill Road diverted around the proposed parking area until connecting to the main trail) was approximately 2,780ft. The trail lengths were calculated using the ArcGIS trail layer created from the site survey and the AutoCAD parking area designs. At a finished width of ten feet, the total finished trail surface area equaled 27,800ft^2. To meet the required design depth of four inches, approximately 345yd^3 of half-inch-minus gravel was needed. At a cost of \$17.50 per cubic yard[10], the total cost of materials to construct the designed trails was estimated to be $6,040. Table 11 summarizes the cost estimation for trail materials. Labor costs are not included in these estimates as volunteer labor is expected to be used.

Table 11: Trail Material Cost Estimation

Trail Length (ft)	2,780
Finished Surface Area (ft^2)	27,800
Required Gravel Material (yd^3)	345
Unit cost of material (per yd^3)	$17.50
TOTAL TRAIL MATERIAL COST =	$6,040.00

4.2 Parking Area

Preliminary parking area design alternatives were presented to the STC at their January 13, 2011 meeting. Feedback from this meeting was used to create two final design alternatives for the trailhead parking area. These final designs incorporated all of the requests of the STC and included the implementation of stormwater best management practices (BMPs) in the form of a gravel infiltration trench. Both final design alternatives are presented in Section 4.2.1, the stormwater BMP designs are presented and discussed in Section 4.2.2, and cost estimations for both designs are summarized in Section 4.2.3.

4.2.1 Design Alternatives

The following sections describe the features of each final parking area design alternative. The features and strengths of the alternatives are compared and evaluated in the Conclusions, Section 5.2.1, and a final design is recommended based on the evaluation.

[10] Unit cost estimate provided by Sturbridge Trails Committee

Design 1

The final revision of Design 1 features 27 parking spaces for passenger vehicles, including one ADA-compliant parking space positioned closest to the main trail entrance. The design does not require repositioning the existing shed or the existing footings for the planned shed. It is recommended however, that vehicle bollards be placed appropriately in front of and beside the sheds to prevent accidental damage from turning or reversing vehicles. This design meets the requirement of the STC by accommodating a ten-foot finished trail width, separate from the vehicle entrance to the parking area. This separate trail connects the entrance at Stallion Hill Road to the main trail at the end of the vehicle parking area by passing along the north side of the lot. Design 1 can be seen in Figure 27.

To discourage unauthorized motor vehicle usage on the trail, vehicle control bollards are recommended at the entrance to the trail. Vehicle curbing is also recommended along the northern parking spaces to prevent vehicles from driving too far forward onto the trail surface. The curbing and bollards can be made from materials currently on the site, including concrete lamp posts and telephone poles. The curbing should be spaced such that pedestrians, bicycles, and wheelchairs can access the trail surface from the parking area unimpeded.

The design of the parking area is laid out so that there is a straight approach from the existing gate at the Stallion Hill Road entrance to the proposed pipe gate at the entrance to the main trail at the far end of the parking area. This direct geometry provides easy access to the trail for construction equipment and maintenance vehicles. A 42-foot radius turnaround area is also included in this design, which will allow up to a 19-foot vehicle with a 30-foot pull-behind trailer to turn around without the need to reverse or execute a three-point turn (FHWA-1, 14). The gravel infiltration trench design, which is discussed in Section 4.2.2, is implemented along the southern border of this design alternative to capture runoff from the parking area. Some hillside excavation will be required to accommodate the finished trail width adjacent to the parking area. Exact estimates of the amount of material required to be excavated were not obtained due to the limited topographic data available for the site. The blue line overlaying the design depicts the 200-foot buffer from the edge of the Quinebaug River, detailed in Section 3.3.3.

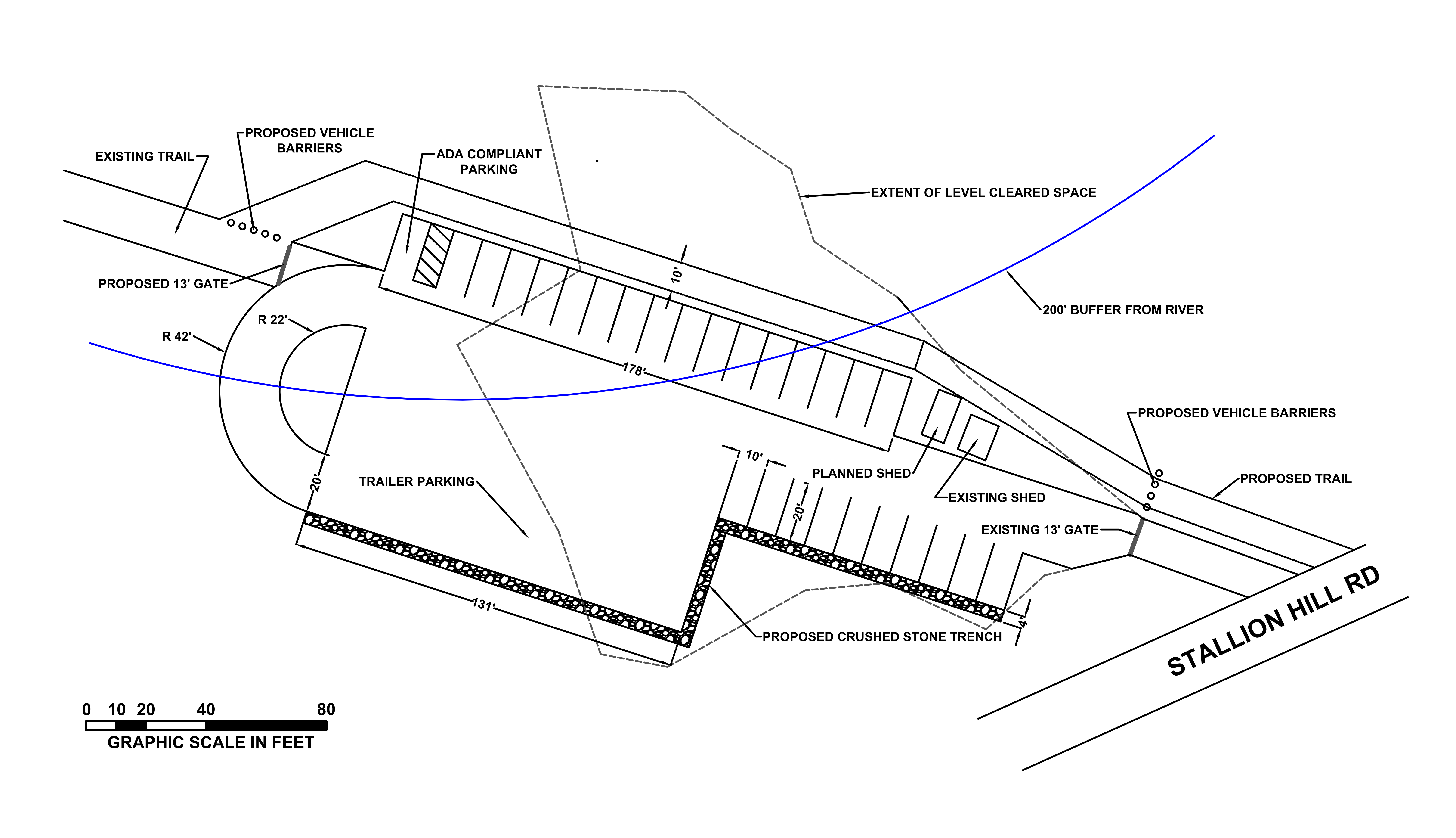

Figure 27: Parking Area Design 1

Design 2

The final revision of Design 2 features 24 parking spaces for passenger vehicles, with two being ADA-compliant parking spaces located immediately adjacent to the main trail entrance. This design alternative incorporates the existing shed and footings for the planned shed and does not require them to be relocated. Design 2 features a finished trail width, separate from the vehicle entrance to the parking area. This trail length connects the trail entrance at Stallion Hill Road to the main trail at the end of the vehicle parking area by passing along the north side of the lot. Design 2 can be seen in Figure 28.

To discourage unauthorized motor vehicle access to the trail, this design recommends vehicle control bollards be placed at the entrance to the trail from the road, as well as at the end of the passenger vehicle parking area. Vehicle curbing is also recommended along the edge of the passenger vehicle parking area to prevent vehicles from driving onto the trail surface and to divide the passenger vehicle area from the trailer parking area. The curbing and bollards can be made from materials currently on the site, including concrete lamp posts and telephone poles.

The design of the parking area is laid out so that there are separate areas for passenger vehicles and equestrian trailers. The separate trailer parking area features a turnaround which will allow a 19-foot vehicle with up to a 30-foot pull-behind trailer to turn around without having to reverse or execute a three-point turn (FHWA-1, 14). This design also features a picnic area for visitors, located in the center of the trailer parking area. The two parking areas should be flagged by clear signage indicating their intended purposes to ensure the safety of trail users. This design features stormwater BMPs, in the form of a gravel infiltration trench (discussed in Section 4.2.2) along the edge of each parking area to capture all runoff from the parking area. Hillside excavation will be required for the finished trail width adjacent to the parking area, and to fit the trailer parking area on the site. Exact estimates of the amount of material required to be excavated were not obtained due to the limited topographic data available for the site. The blue line seen on the design represents the 200-foot buffer from the bank of the Quinebaug River, as described in section 3.3.3.

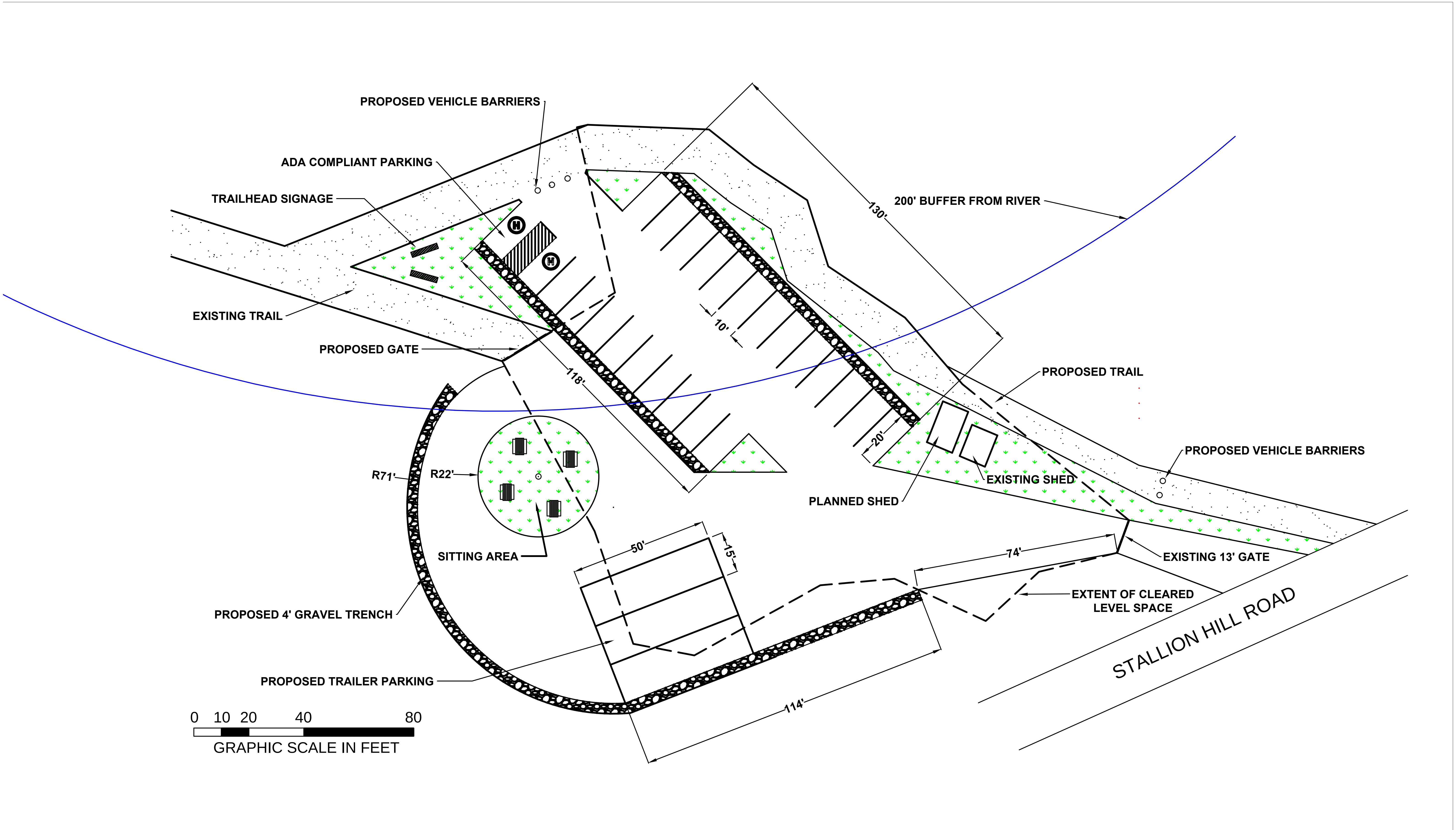

Figure 28: Parking Area Design 2

4.2.2 Stormwater Best Management Practices & Parking Surface

To satisfy the requirement of the STC of incorporating stormwater BMPs into the design of the trailhead parking area, a gravel infiltration trench was designed. The design is modeled after runoff controls implemented at another STC project site, the Arbutus Park Trail located at 10 Old Sturbridge Village Road, which features a similar trailhead parking area. Figure 29 is a cross section of the gravel infiltration trench, detailing its construction. The trench design is 48in wide and 42in deep, filled with 1 ¼ inch crushed stone. It is recommended that the trench be lined with filter fabric to minimize silt and fines from filling the void space between the stone which would decrease the potential infiltration of the trench. These deposits could also be minimized by filling the top of the trench with crushed stone of a smaller nominal aggregate size.

Cross Grading

The trench is designed to capture and filter stormwater runoff from the parking area, including vehicle pollution and horse manure. In order to minimize water sitting on the parking area surface and to avoid excessive mud formation, both parking area design alternatives feature a three percent cross grade. This grade was selected to maximize runoff potential, while still maintaining a safe grade for ADA accessibility and the unloading and mounting of equestrians.

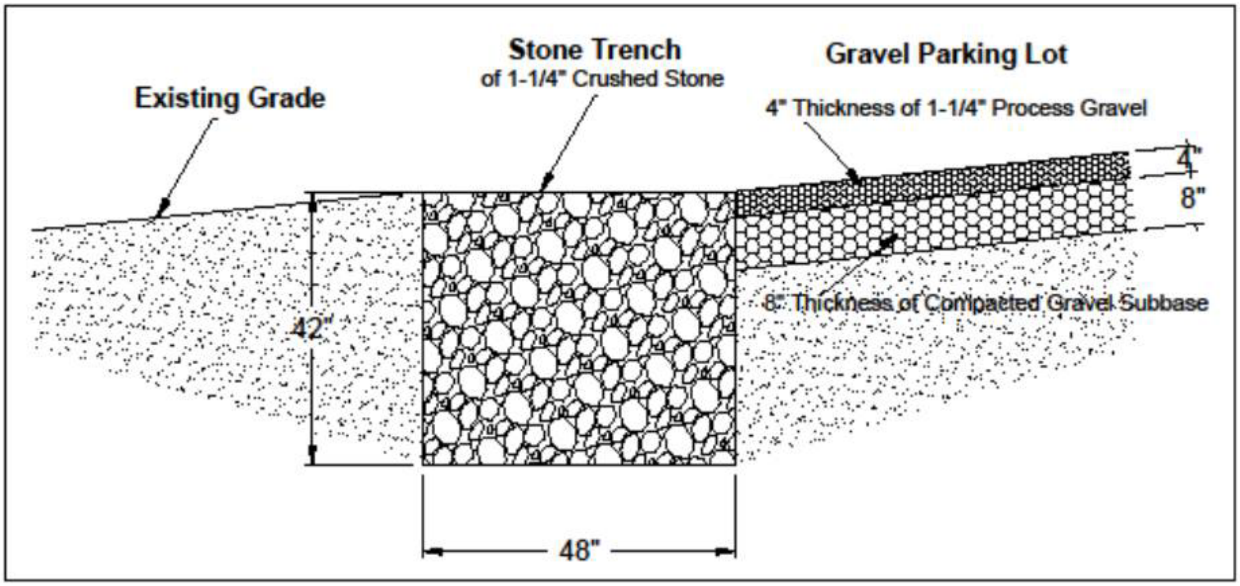

Figure 29: Gravel Infiltration Trench Cross-section

Parking Surface Materials

The parking surface was also designed to meet the requirements of the STC. The parking area consists of an eight-inch subbase layer of compacted gravel. The subbase is overlaid with a four-inch layer of 1 ¼ inch process gravel. This design facilitates additional infiltration through the parking surface while providing a stable and easily maintained base to support vehicles and equestrians. It is recommended that smaller aggregate gravel, such as the half-inch-minus gravel specified for the trail surface, be used for the surface of the ADA-compliant parking spaces because a finer material will have better compaction and therefore reduced shifting, which is beneficial to wheelchair users.

4.2.3 Cost Estimation

Separate cost estimations were performed for each parking area design alternative in order to evaluate them from an economic standpoint. Items included in the estimations consisted of the required material for the designed eight-inch compacted gravel subbase of the parking area, the four-inch processed gravel top layer, the crushed stone fill for the gravel infiltration trench, and the cost of any vehicle gates required by the designs. The unit cost estimates were provided by the Sturbridge Trails Committee.

Cost of Design 1

The total finished surface area for the parking area in Design 1 was 22,550ft^2. Table 12 summarizes the material costs for this design alternative. The design specified a compacted gravel subbase depth of eight inches, amounting to a total of 557yd^3 of subbase material. At a price of $10.00 per cubic yard, the required subbase materials cost $5,570. The required amount of material for the four-inch top surface of process gravel for this design alternative was 278yd^3. At an estimated $17.50 per cubic yard, the process gravel for the top surface layer of the parking area will cost $4,870. The gravel infiltration trench of Design 1 had a total surface area of 1,085ft^2. At a design depth of 42in, the required crushed stone fill for the trench was 141yd^3. The crushed stone fill would cost $1,410 at $10.00 per cubic yard. The design also required one additional pipe gate to be added to the site in order to restrict vehicle access from the parking area to the main trail, at an estimated cost of $200. The total price of construction materials for Design 1 came to an estimated $12,000.

Table 12: Parking Area Design 1 Materials Cost Estimation

Material	Quantity	Unit Price	Cost
Subbase Compacted Gravel (yd^3)	557	$10.00	$5,570.00
Top Surface Process Gravel (yd^3)	278	$17.50	$4,870.00
Infiltration Trench Crushed Stone (yd^3)	141	$10.00	$1,410.00
Pipe Gate	1	$200.00	$200.00
TOTAL PARKING AREA MATERIAL COST =			**$12,000.00**

Cost of Design 2

Parking Area Design 2 required a total finished surface area of 24,730ft^2. Table 13 summarizes the material costs for this design alternative. The parking lot surface featured a compacted gravel subbase design depth of eight inches, which required a total of 611yd^3 of subbase material. At $10.00 per cubic yard, the subbase compacted gravel would cost $6,110. The amount of top surface process gravel required to achieve the four-inch depth for this design alternative was 305yd^3. At an estimated $17.50 per cubic yard, the process gravel for the top surface layer would cost $5,340. The gravel infiltration trench specified in Design 2 had a total surface area of 2,013ft^2. The required crushed stone to fill the trench to the design depth of 42in was 261yd^3. The crushed stone at a unit price of $10.00 per cubic yard would cost $2,610. This design alternative also called an additional pipe gate to control vehicle access to the main trail, which would cost an estimated $200. The total price of construction materials for Design 2 came to an estimated $14,300.

Table 13: Parking Area Design 2 Materials Cost Estimation

Material	Quantity	Unit Price	Cost
Subbase Compacted Gravel (yd3)	611	$10.00	$6,110.00
Top Surface Process Gravel (yd3)	305	$17.50	$5,340.00
Infiltration Trench Crushed Stone (yd3)	261	$10.00	$2,610.00
Pipe Gate	1	$200.00	$200.00
		TOTAL PARKING LOT MATERIAL COST =	**$14,300.00**

4.3 Culvert Replacement

Two alternatives were explored for the culvert replacement: a pipe culvert for ease of installation and a box culvert for a reduced impact on the ecology of the site. The design of the culvert required multiple intermediary steps. These steps accounted for hydrological, hydraulic, and structural considerations.

The recommendation for the pipe culvert was fully designed with respect to hydraulic and structural considerations. The box culvert design was completed with respect to hydraulic consideration but only partially designed for structural considerations. This affects the comparison between designs when evaluating the alternatives since accurate cost estimation could not be performed without detailed structural designs for the box culvert. Also, if the box culvert design is selected a more detailed structural analysis will need to be performed by a Professional Engineer. The results of each alternative are presented in this section.

4.3.1 Hydrological Analysis Results

Hydrological analysis of the contributing watershed was required for the hydraulic design of the two culvert alternatives and to calculate required storage of the culverts in a 25-year rain event. The hydrological calculations were performed using the NRCS Technical Release 55 Manual (TR-55). The TR-55 Graphical Peak Discharge Method produced a peak 25-year rain event flow from the contributing watershed to the culvert inlet. The TR-55 Tabular Hydrograph Method was used to construct a hydrograph showing the flow from the watershed to the culvert inlet over the duration of the rain event. The value for peak flow is 136cfs. The hydrograph can be seen in Figure 19. These calculations can be seen in full in Section 3.5.1.

4.3.2 Pipe Culvert Hydraulic Analysis Results

The peak flow from the hydrological analysis was used for the hydraulic design of the culvert alternatives. The hydraulic calculations produced a maximum flow that the culvert was capable of passing. The resulting maximum flow capacity of the pipe culvert is 96.7cfs. The full calculations are performed in Section 3.5.6.

The flow capacity of the pipe culvert is less that the peak flow from the watershed; therefore, a portion of the stormwater runoff will remain upstream of the culvert in the watershed. This volume of water is considered the required storage behind the culvert. This water will be stored in the wetlands upstream of the culvert. The required storage was determined by plotting the maximum flow capacity of the pipe with the hydrograph from hydrological calculations. The maximum flow capacity of the pipe represents the maximum outflow of the system and the hydrograph represents the expected inflow of the system over the duration of the rain event. This inflow/outflow hydrograph can be seen in Figure 30.

The available storage volume was determined using the allowable headwater height and wetland area. The wetland area was determined within ArcGIS using MassGIS contour data and the wetland boundaries. The required storage was determined to be less than the available storage; therefore the hydraulic design for the pipe culvert was adequate. The summary of these calculations can be seen in Figure 30. The complete procedure for calculating storage is described in Section 3.5.6.

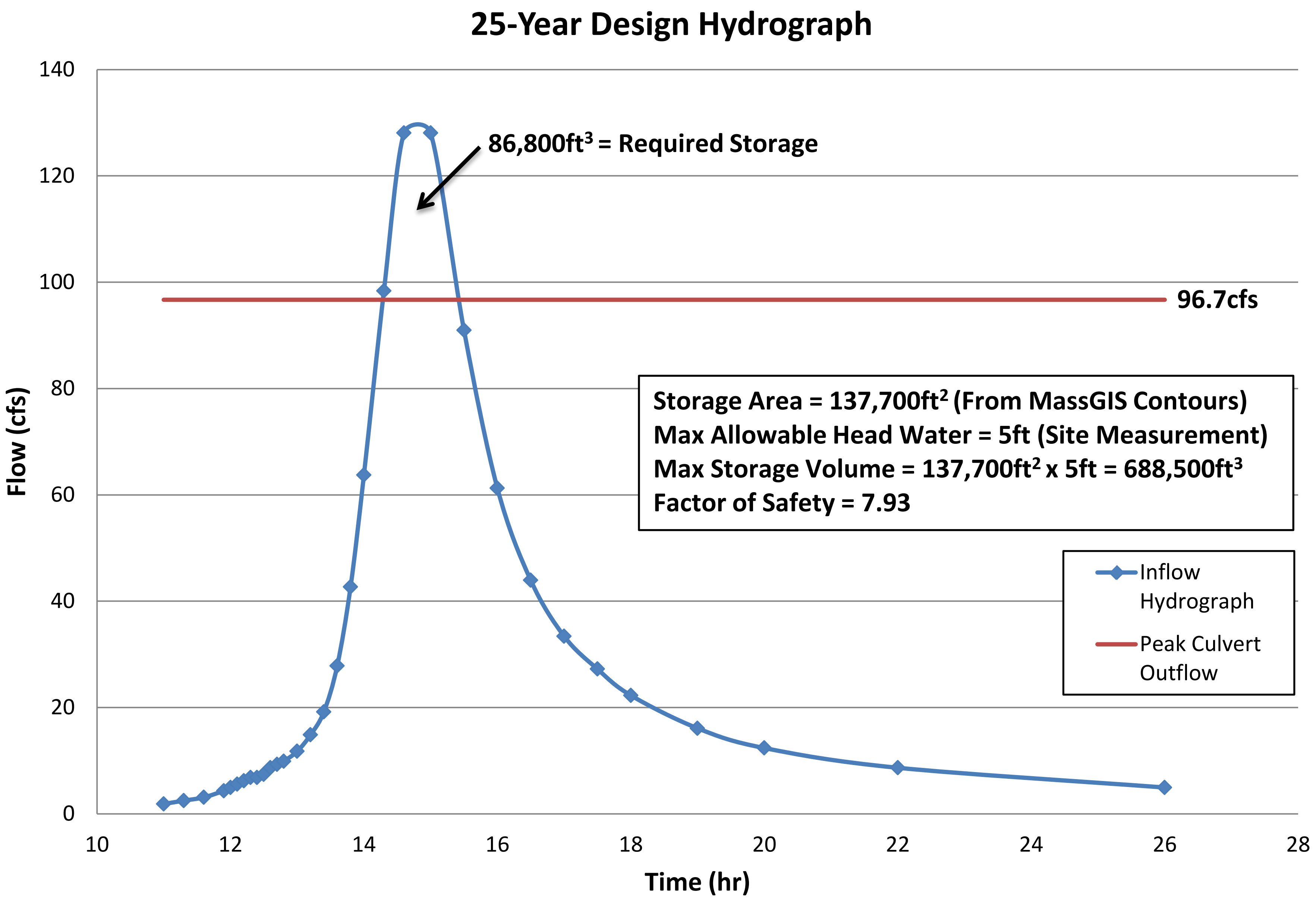

Figure 30 : Pipe Culvert Inflow/Outflow Hydrograph Showing Storage

4.3.3 Pipe Culvert Design Results

The results of the pipe culvert design are the culvert material selection and the cross section geometry for installation. This design is based on hydrological and hydraulic calculations as well as recommendations from ADS, the manufacturer's design guide. The flow carrying portion of the culvert is an ADS 48-inch nominal Dual Wall, smooth lined, N-12 High Performance Storm pipe. A cross section of the pipe culvert can be seen in Figure 31. The bottom inner surface of the culvert will be recessed 12in below the existing stream bed to account for sediment fill. Sediment from the stream bed will be used to cover the bottom 12in of the interior diameter of the culvert to match the height of the existing stream bed. This will act as a semi-natural bottom to allow for wild life passage.

Structural considerations for the culvert required capacity for an AASHTO H-20 loading. A cover depth of 36in above the culvert will support an AASHTO H-25 loading according to the ADS design guide. A five-inch trail surface is designed above the three feet of cover. This is an increase from the four inch thick surface on the other portions of the trail to account for rutting and trail wear. The minimum installation trench width and soil layer information came from the ADS design guide based on the depth and size of the pipe. An investigation of onsite soil properties will be needed to determine the precise aggregates for bedding and fill materials.

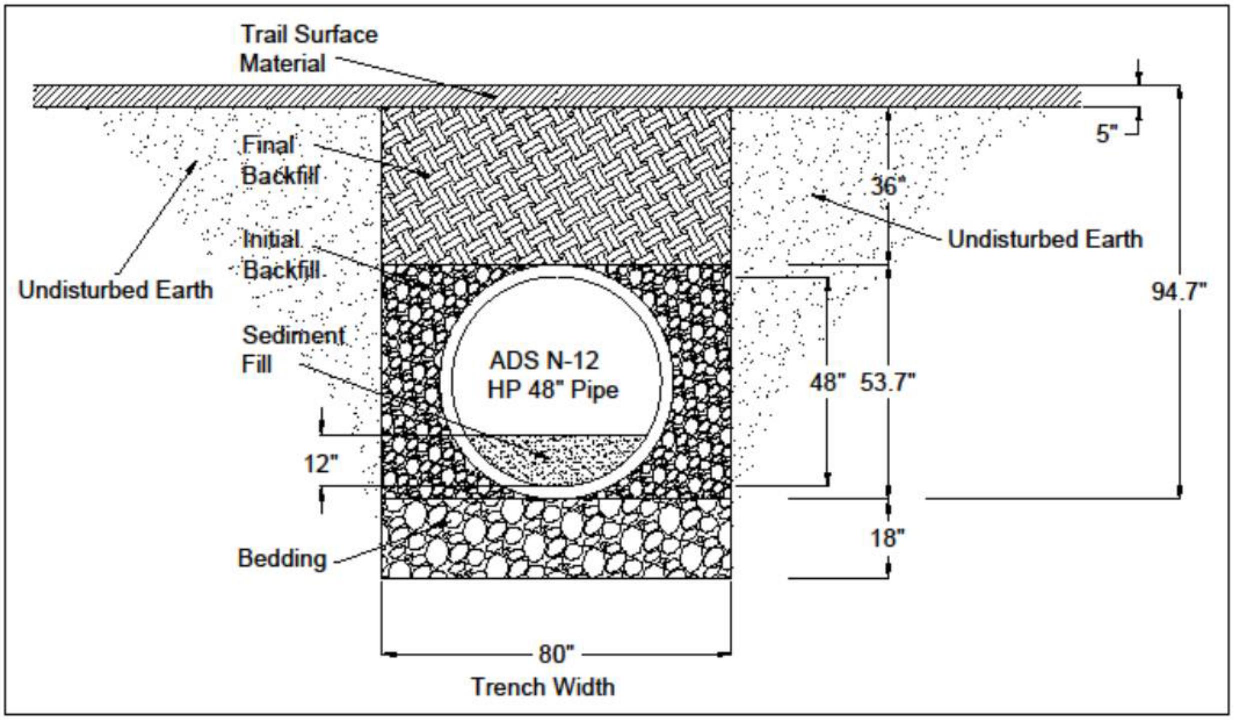

Figure 31: Pipe Culvert Cross Section

The culvert installation will require supporting side slopes on the inlet and outlet of the culvert to stabilize the trail and culvert fill. The side slope will be approximately three to one, created from on-site soils and armoring materials. The armoring materials will serve as riprap and should be composed of crushed concrete rubble, concrete lampposts and other materials recovered from debris on the site. Groundcover plants such as pachysandra can be used to hide the riprap.

An overall culvert length of 34ft will account for the ten foot standard trail width, shoulders of two and four feet, guardrails, and side sloped earth to support the trail. A summary of culvert properties can be seen in Table 14.

Table 14: Summary of Pipe Culvert Properties

Length	34 Feet
Trench Width	80 Inches
Cover Depth	36 Inches
Side Slope	3 : 1
Armoring	Recycled Onsite Concrete Rubble
Pipe	48” ADS N-12 HP Storm Pipe. Polyethylene, dual wall, corrugated, smooth lined.

4.3.4 Concrete Box Culvert Design Results

The box culvert design provides estimated cross section geometry for installation. The hydraulic analysis for the box culvert led to the selection of a three-foot high by four-foot wide internal cross sectional area. These dimensions resulted in a design with no required storage. The complete hydraulic calculations can be seen in Section 3.5.7.

Recommendations for general shape, material, and cover of the culvert came from the MassDOT 2005 Bridge Manual. The box culvert will be a flat top, three-sided box made of precast concrete panels. A five-inch trail surface is designed above the three feet of cover. This is an increase from the four-inch thick surface on the other portions of the trail to account for rutting and trail wear. An estimated cross section of the box culvert can be seen in Figure 32. This cross section was created to represent a concrete box culvert within the geometry of the trail crossing.

Similar to the design of the pipe culvert, installation of the box culvert will require supporting side slopes on the inlet and outlet of the culvert to stabilize the trail and culvert fill. The side slope will be approximately three to one, created from on-site soils and armoring materials. The armoring materials will serve as riprap and should be composed of crushed concrete rubble, concrete lampposts and other materials recovered from debris on the site. Groundcover plants such as pachysandra can be used to hide the riprap.

An overall culvert length of 34 feet will account for the ten-foot standard trail width, shoulders of two and four feet, guardrails, and side sloped earth to support the trail. Concrete reinforcing and concrete dimensions have not been designed because the selection of a concrete box culvert was discouraged by the Sturbridge Trails Committee early on in the culvert design process. Further design is required before the box culvert can be constructed. This design work should be in compliance with the most recent edition of the MassDOT Bridge Manual. A summary of culvert properties can be seen in Table 15.

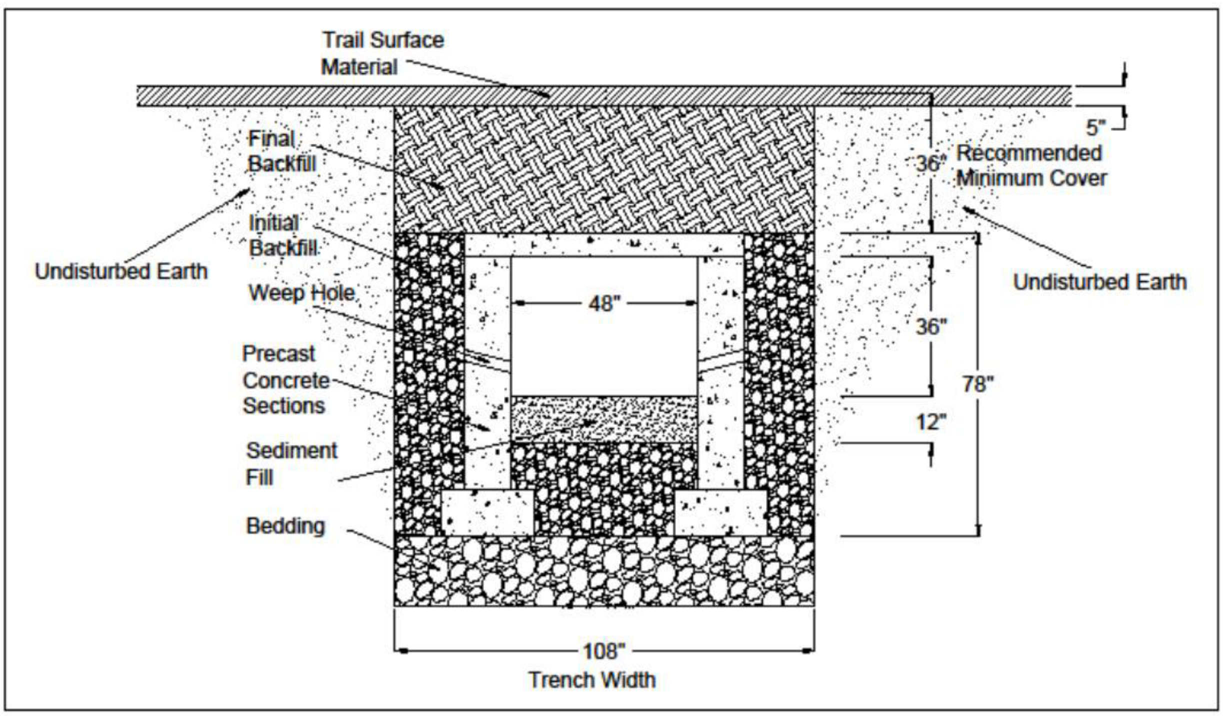

Figure 32: Box Culvert Cross Section

Table 15: Summary of Box Culvert Properties

Length	34 Feet
Cover Depth	36 Inches
Side Slope	3 : 1
Armoring	Recycled Onsite Concrete Rubble
Box	36" High, 48" Wide, Flat Top, Three Sided, Precast Concrete

4.3.5 Guardrails

It is recommended to install guardrails on the trail at the culvert crossing because of the abrupt change in elevation from the trail surface to the riverbed. Guardrails will protect pedestrians, cyclists, horses, and vehicles from falling off the trail. They also encourage trail users to stay on the finished portion of the trail. The guardrails should be installed between the shoulders of the trail and the riprap stabilizing the trail at the culvert crossing. They should be present on both sides of the trail and extend sufficiently beyond the culvert crossing in both directions.

4.3.6 Cost Estimation

Cost estimation was performed only for the pipe culvert because the box culvert alternative was discouraged early in design. A sales representative from the manufacturer, ADS, was contacted by telephone in April, 2011 for pricing quotes. The representative noted that these price quotes are higher than would be expected for actual construction costs. The ADS pipes are manufactured in Ludlow, Massachusetts and sold through distributors. A summary of price information for the selected ADS 48” N-12 HP Pipe can be seen in Table 16.

Table 16: Summary of Pipe Price Information

Cost Per Foot	$70
Length	34ft
Pipe Culvert Cost	**$2,380**

5 Conclusions

The following section contains the summation of the work performed for this project. The final trail design is discussed. The two parking lot designs are evaluated side by side, and a final recommendation is selected. The two culvert design alternatives are also evaluated, with a final design recommendation being made. Opportunities for future work for all three sections are explored, and a total cost summary for all of the final design recommendations is included.

5.1 Trail Design Conclusions

The trail design produced considerations and designs for the trail including layout, clearing, grading, surfacing, and stormwater best management practices. A total trail length of 2,780ft was designed. These designs can be seen in detail in the Results, Section 4.1. The following section outlines opportunities for future work that could be performed to improve the trail design.

5.1.1 Future Work for the Trails

There are issues still to consider with the design and installation of the trail. Soil testing along the trail length should be performed to ensure proper strength of the soil to accommodate the expected traffic loading. Retaining walls should be considered to stabilize portions of the trail especially where excavation and fill are required. Guardrails should be considered for portions of the trail with steep side slopes to protect trail users. Signage should also be posted to guide visitors along the trail.

5.2 Parking Area Design Conclusions

The two final design alternatives created for the trailhead parking area were evaluated based on their usability, constructability, and, subsequently, cost. Based on this evaluation, a single design alternative was selected as the final design recommendation to the Sturbridge Trails Committee. The evaluation criteria and final selected design are discussed in the following sections.

5.2.1 Evaluation of Parking Area Alternatives

In order to select a final design recommendation from the two parking area designs, certain qualifying criteria had to be addressed. These criteria were divided into two categories: constructability criteria which subsequently dictate cost, and usability criteria, some of which also affects the safety of the parking area.

Constructability

Constructability, or the relative ease which each parking design could be constructed, was an important consideration in selecting a final recommendation. Constructability not only encompasses the required materials for the design, but also the amount of time and work that will be necessary to complete the project. Simple grading was determined to be a desired feature in the parking area design, along with requiring less finishing materials for the parking area surface. Requiring less hillside excavation and leveling would reduce the construction effort, and was deemed a positive quality. Finally, requiring less vehicle curbing would reduce the labor of placing curbing, and possible costs associated with the procurement of curbing if suitable materials could not be found on the site.

Usability

The usability of the parking area was determined by analyzing the layout geometry, capacity, and safety features of the design alternatives. The desired criteria for usability included a separation of trailer parking from passenger vehicle parking at the request of the STC, higher capacities for both trailer and passenger vehicles, and greater accessibility to the trail. Accessibility included having more ADA-compliant parking spaces, and a direct route for maintenance and construction vehicles to access the trail. Finally, since the parking area will not be marked with lines, simple, rectangular parking alignment was considered more desirable to limit the possible orientations in which drivers may park. The design alternative that best met each criterion is summarized in Table 17.

Table 17: Summary of Parking Area Design Evaluations

Evaluation Criteria	Design 1	Design 2
Constructability		
Simpler Grading	✓	
Less Excavation	✓	
Less Materials	✓	
Less Curbing	✓	
Usability		
Separation of Trailer Parking		✓
Larger Horse Trailer Capacity		✓
Larger Passenger Vehicle Capacity	✓	
More ADA-Compliant Spaces		✓
Direct Access for Maintenance Vehicles	✓	
Simpler Parking Alignment	✓	

5.2.2 Final Design Selection

Based on the evaluation of the parking lot alternatives, Design 1 was selected as the final design recommendation to be presented to the STC. This design was chosen because it was evaluated to be more easily constructible, required less construction material, was more economical than the alternative design, and adequately met the usability requirements of the STC.

5.2.3 Future Work for Parking Area

Additional design work that was not included in this project but could be incorporated into the trailhead parking area includes location of signs; selection of vehicle bollards, curbing and gates; and a structural analysis of the parking surface. Selection of the appropriate placement for parking area signage would improve the efficiency of the parking area and also increase user safety. Possible options include ADA-compliant parking space signs, a "trailer parking only" sign to designate the horse trailer area, an entrance sign identifying the site, and a sign marking the entrance to the main trail. It was recommended that materials be procured on site that would meet the requirements for vehicle bollards and curbing, but if suitable materials are not found, then selection of materials to be purchased for these as well as the type of gate to be purchased should be made. An in-depth analysis of the structural loading capacity of the designed parking area surface, and the underlying grade could be performed to ensure that the surface will sustain the loading of expected vehicle usage.

5.3 Culvert Design Conclusions

The goal of the Sturbridge Trails Committee is to replace the culvert with a durable culvert that will have a minimal impact on the surrounding wildlife and ecosystem. To fulfill this goal, research was performed to gather information about culvert types, hydrology, hydraulics, and structural ratings. Two alternatives were designed for the culvert replacement: a concrete box culvert for a reduced impact on the ecology of the site, and a corrugated plastic pipe culvert for ease of installation.

5.3.1 Evaluation of Culvert Alternatives

The three-sided, precast-concrete box culvert alternative has a low impact on the surrounding ecosystem, but is more difficult and intrusive to construct. The natural, open bottom of this alternative disturbs the streambed as little as possible. This design does not require storage and would not have a noticeable effect on water velocity. The excavation trench to install the box culvert and foundation footings will have to be deeper and wider than for the corrugated pipe. For these reasons the box culvert alternative best meets the Sturbridge Trails Committee goal of minimally impacting the surrounding ecosystem, but will be more complicated to construct as well as intrusive and most likely more expensive to install.

The corrugated plastic pipe culvert alternative is a simple design which will be easy to construct and install but alters the streambed and will require storage during high-flow-rain-events. The sediment backfill acts as a natural bottom but not as an open bottom and therefore might not accommodate all streambed life.

5.3.2 Final Design Selection

The pipe culvert was recommended for use on the Riverlands site based on ease of installation and construction although it does not feature an open bottom. This design can be seen in detail in Section 4.3.3.

5.3.3 Future Work for Culvert

There are issues still to consider with the design and installation of the culvert. Soil testing should be performed to ensure proper strength of the soil surrounding the culvert. Further research should be conducted into the durability of the culvert sediment fill and its effect on streambed life to ensure ecosystem protection. Guardrails should be selected for use on the culvert to protect trail users. Alligator teeth or other outflow controls should be investigated to protect against outflow scouring and erosion issues. Increased hydrological analysis should be performed to account for development in the watershed and inflows to the watershed.

5.4 Final Cost Estimation of Design Recommendations

The total cost summary of the final design recommendations for each portion of the project are presented in Table 18 below.

Table 18: Total Cost Summary of Design Recommendations

Project Design Recommendation	Cost
Trail Surface	$6,040.00
Parking Area	$12,000.00
Pipe Culvert	$2,380.00
TOTAL COST OF RECOMMENDATIONS =	$20,420.00

These cost estimations include the prices of the materials required to construct each portion of the design. Unit cost estimates for the trail and parking area surface materials were provided by the STC. The estimates do not include the price of equipment rental required to construct the site, any contract labor required, transportation costs, or the cost of a Professional Engineer's review.

5.5 Next Steps

There are more steps that can be taken to further develop or improve the Riverlands site. These additional recommendations address safety, promotion, expanded usage, integration into the Titanic Rail Trail system, and financing of the project. Due to the extent of litter and dumping present on the site, testing for soil contamination throughout the site is recommended, prior to development, in order to ensure public safety. Before construction can begin on the site the designs must be approved by a Professional Engineer and the Sturbridge Conservation Commission. In order to maximize the benefit of this project to the residents of Sturbridge, public outreach and promotion of the site should be performed to increase the publics' awareness and encourage greater usage by the community. Further options for additional trails on the site can be explored, including usage-specific trails for mountain biking or hiking. These would not be required to meet ADA standards. Additionally, a trail network could be created to connect the main trail to future picnic and recreation areas on the site.

In order to connect the designed trail to the planned Titanic Rail Trail on the west side of the Riverlands site, at Holland Road, an additional parcel must be acquired by the Town of Sturbridge before further development of the trail can commence. To connect the designed trail to the planned Titanic Rail Trail on the east side of the site, the trail needs to be extended from the trail entrance along Stallion Hill Road to Old Sturbridge Village Road in the east. Prior to development, sufficient funding must be obtained by the STC to cover the costs of materials, equipment, and labor. An additional cost for this project is the price of a Professional Engineer's review of the designs.

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Appendices

Appendix A – Project Proposal

STURBRIDGE TRAIL DESIGN

A Proposal for a Major Qualifying Project Report:

Submitted to Faculty of

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

By

Devon Ward

Walter Woodington

Date: October 14, 2010

Approved:

Professor Suzanne LePage, Advisor

Professor Leonard D. Albano, Co-Advisor

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Problem Statement

The Town of Sturbridge is seeking to improve and expand their public recreational trail system. A portion of the Grand Trunk Trail travels through the Town of Sturbridge. This section is unfinished, and the town citizens and government would like to see the quality of the trail improved so it can be properly used by the residents of the area. The issues to be addressed that are preventing the section of trail from being officially recognized and widely used include the need for trailhead parking, grading and clearance issues, replacement of a washed-out culvert, implementation of erosion controls, and selection of an appropriate trail surface.

Objective

The purpose of this project is to present designed solutions for completing a portion of the Grand Trunk Trail adjacent to the Old Sturbridge Village within the Town of Sturbridge. The existing problems of the trail will be analyzed and solutions will be designed to meet the requirements of the Sturbridge Trails Committee and comply with all governing regulatory standards. Multiple design options for the culvert and parking area will be prepared. Evaluation criteria will be established based on cost, constructability, safety, and environmental impact. These criteria will aid in selecting which design alternatives are to be recommended to the Sturbridge Trails Committee. Grading, clearance, erosion and surfacing issues will be addressed in the design proposal for the entire site. Each design alternative and the site proposal will be presented to the Town Administrator and the Sturbridge Trails Committee.

Scope of Work

The responsibilities of the project will be divided between the team members based on their respective areas of interest and skills. The project will be divided into five main phases: identification, categorization, analysis, design and presentation. Identification will be conducted through site visits and meetings with the project contacts on the Sturbridge Trails Committee. These visits and meetings will assist in assessing trail conditions and identify existing problems.

The information collected from the identification phase will be used to start categorization of problems and issues. The trail will be broken into sections along its length based on area-specific issues. These issues will then be listed and categorized for each section. The analysis of issues on the trail will be limited to the length from the entrance on Stallion Hill Road, as shown in Figure 1, to the gravel pit, following the path designated by the Trails Committee. This length of trail will be analyzed for grading, clearance, erosion and surfacing issues. Solutions to these issues will be designed in the next phase.

Figure 1: View of existing trail from Stallion Hill Rd

The project will include two designs for a replacement of the washed-out culvert on the trail as well as two designs of a parking area at the entrance to the trail. These designs will be evaluated and rated on a basis of cost, constructability, safety, and environmental impact. Using these criteria a recommended design for both the culvert and parking lot will be selected. The final trail site designs will be presented to the Town Administrator and the Sturbridge Trails Committee.

Background

Culvert background

There is a washed-out culvert approximately a quarter of a mile from the entrance to the trail at the Sturbridge site. The existing culvert is a three foot diameter riveted iron pipe 27 feet long sitting at the bottom of the washed out area in the trail approximately 10 feet deep and 20 feet across. This can be seen in seen in Figure 2 below. This culvert was constructed as part of a greater railroad project called the Grand Trunk Railroad. It was washed out during a flood in 2005 and is an obstacle preventing higher use and better maintenance of the trail.

Figure 2: Washed-Out Culvert Sept. 2010

The Town of Sturbridge, the Trails Committee, and the Conservation Commission would like to replace this washed out culvert as a step towards creating a finished trail and recreation area at this site. The desire is to maximize accessibility for the visitors while minimizing the impact on the surrounding wildlife and ecosystems. To accomplish this, the Conservation Commission would prefer to replace the culvert with an open bottom style rather than the previously used tube style. An example of a tube style as well as an open bottom culvert can be seen in Figure 3 and Figure 4 below. An open bottom culvert was a requirement on past projects in the town and will be especially important on this project site because the culvert is located in a wetland area which should not be disturbed. The wetland is covered by The Wetlands Protection Act and the only reason that this culvert can be constructed is because it is classified as maintenance to the previously existing culvert in the same location.

 [i] 

[ii]

Figure 3: Open Bottom Style Culvert

Figure 4: Tube Style Culvert

Another requirement for the culvert comes from The Sturbridge Trails Committee's future plans for this site. They would like to develop this area further and require that logging trucks be capable of crossing the culvert. This requires an AASHTO Highway 20 rating. This rating would also cover any maintenance vehicles that would need to cross the culvert once the site is fully developed. The width of the culvert will match the width of the trail which will accommodate these logging trucks and other maintenance vehicles. The culvert will also feature required guard rails as well as any hand rails required by the Americans with Disabilities Act (ADA). The culvert will have a total clear crossing width between the guardrails and handrails of 16 feet and a minimum finished surface width of 10 feet which leaves room for a two foot and a four foot shoulder on each side.

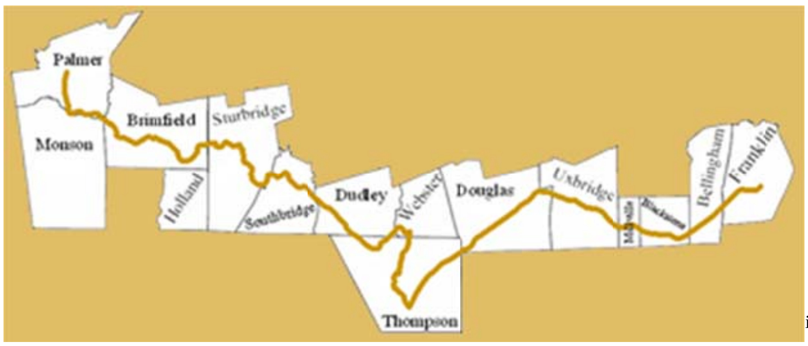
Trail background

The entire length of the trail being designed will be the same 16 foot width similar to the culvert with a 10 foot finished traveling surface and two foot and four foot shoulders. These are the dimensions that The Sturbridge Trails Committee would like to use to accommodate twoway travel for various modes of unmotorized traffic such as pedestrians, horses, bicycles, and wheelchairs. The trail should be finished in a similar manor to other trails in Sturbridge using packed gravel under half an inch and rock dust for the traveling surface.

The path of this trail was predetermined by the wishes of the Trails Committee and runs along an already partially cleared section along the site. This cleared section and the future trail will have to be distinguished from an oil pipeline and power lines that run though the site. This will be accomplished using gates or other barriers to discourage visitors from traveling off of the finished trail. The course of the trail may be altered to avoid wetlands for their protection under the Wetlands Protection Act. Another obstacle that may affect the course of the trail is an ADA slope requirement and a recommendation of the Trails Committee to keep the maximum grade under five percent if possible to accommodate people with disabilities.

History of the Grand Trunk Trail

The original path of the railroad on which this trail is based was determined over 100 years ago in the early 1900's by a hopeful Canadian railroad company that wished to build a railroad, named the Grand Trunk Railroad. The goal was to connect their existing railroad in Vermont to an ocean port in Providence, Rhode Island running across much of southern Massachusetts. This planned railroad passed though both Brimfield and Sturbridge to get there. Most of the rail bed was graded and many of the river crossings were built, before the railroad was abandoned, a couple years after the tragic death of the projects largest funder and president, Charles M. Hays, aboard the Titanic. Today much of the trail has been reclaimed by vegetation and sits relatively unused. A nonprofit organization, aptly named the Grand Trunk Trailblazers, wishes to change this by redeveloping the rail bed into a 60 to 80 mile long non-motorized recreation trail to link the Blackstone and the Pioneer Valleys. This new trail would be called the Titanic Rail Trail, ironically named after the vessel that stopped the railroad from being completed. The proposed route of the Trail can be seen in a map created by The Grand Trunk Trail Blazers as Figure 5 depicts below.[iii]



[iii]

Figure 5: Proposed Route of Titanic Rail Trail in Southern MA

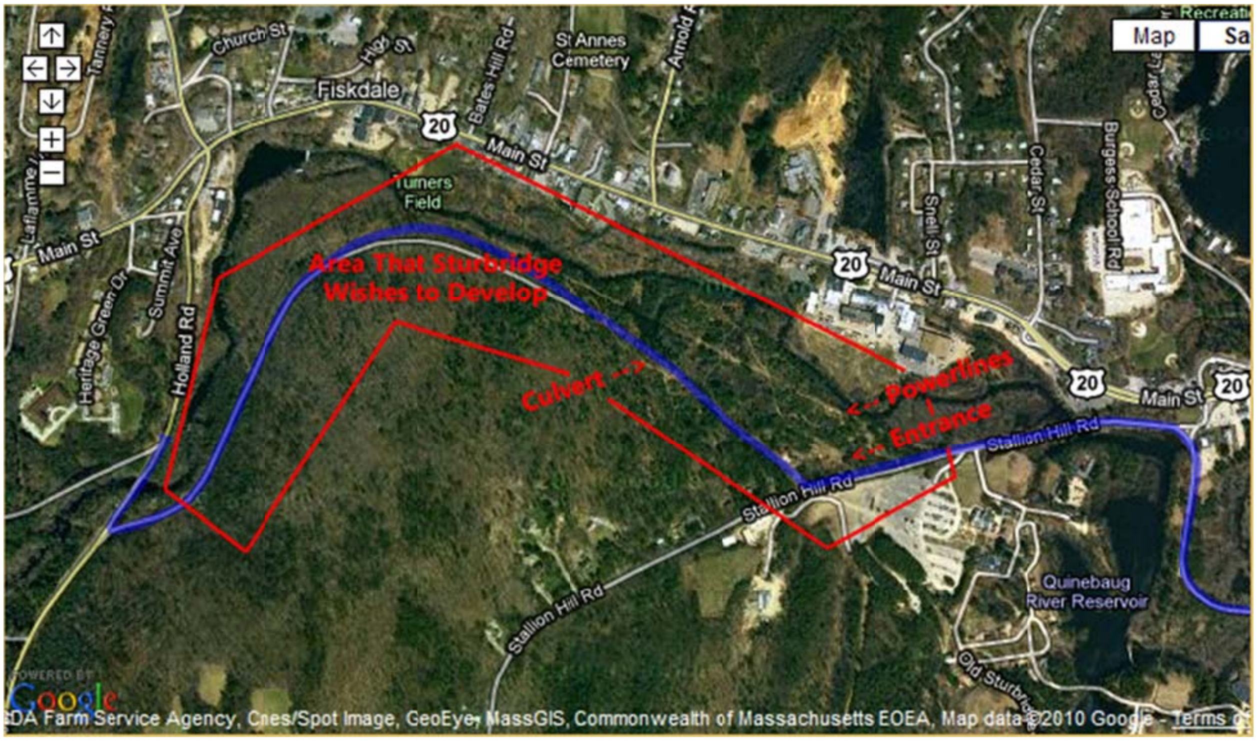


Figure 6: Route of Railroad Bed though Sturbridge Site

Figure 6 shows the site that The Sturbridge Committee wishes to develop next. The blue line in the figure shows the path of what was at one time part of the uncompleted Grand Trunk Railroad. The committee expects that once completed the Sturbridge portion of the trail will someday be reconnected to the rest of the unfinished Railroad in neighboring towns to become the trail system proposed by the Trailblazers[iv] and this should therefore be reflected in the design of the trail section in Sturbridge. Sometime after the railroad project was abandoned a local entrepreneur bought the land surrounding the section of trail in Sturbridge with the plan to excavate and sell some of the gravel used to grade the proposed rail bed. Some of this gravel was mined out ruining the once uniform grade of the site. An example of this removed gravel affecting the trail grade can be seen in a photo from the site seen below as figure 7.

Figure 7: Open Face of Gravel Pit Sept. 2010

Parking lot design constraints

The design for the parking area is controlled and limited by four main factors these are: the expected usage, environmental protection, maintenance facilities, and though traffic on the trail.

Once fully developed as a recreational area this site is expected by the trails committee to get similar usage as a previously developed trail around Westville Lake in East Brimfield. The trail around Westville Lake uses beam counters to track the visitors to the site. During the summer usage reaches up to 350 people per day and the parking lot is frequently filled to capacity. From this usage information it is estimated that the parking lot at the site in Sturbridge should have 20 to 30 parking spaces and should be able to accommodate horse trailers. Parking lot safety could include lighting but because the trail will be open only from dawn to dusk, lighting for the parking lot and trail will not be required.

The parking area must be kept away from the wetlands to follow the regulations of the Wetlands Protection Act and as an extra environmental precaution the Sturbridge Conservation Commission would like to see parking lot stormwater runoff best management plans implemented. This could include a gravel gully surrounding the parking area to catch and filter oils and other potentially hazardous materials coming off of the cars on to the parking lot and then into the stormwater. This can be modeled off of such as system which has been implemented in a recently completed trails project nearby in Sturbridge.

An existing maintenance shed located by the entrance to the trail is another limit on the location and size of the parking area. This shed can be seen in Figure 9 below. The foundation has already been placed for a second similar shed which is planned to be constructed just to the left of the existing one.

Figure 8: Existing shed that parking lot must be designed around

The trail will hopefully become part of the larger Titanic Rail Trail so the parking area should not interfere with through traffic on the trail. Instead the parking area should be built to once side of the trail and this poses the third main restriction on the parking area.

Overview of Committees and Approval Process

There are multiple public entities that are involved in the planning of the trail on in the Sturbridge site. These public entities exist to provide guidance for trail planners, create restrictions to protect the wildlife and environment, look out for the best interests of the town and standardize trails within the region.

The site on which the trail is being constructed is owned by the Town of Sturbridge and therefore is the responsibility of the Town Administrator, Shaun A. Suhoski.[v] The Town Administrator's responsibility is to look out for the best interests of the town and therefore must inspect and approve all plans and developments associated with town property including any of the development plans recommended for this trail site.

The Sturbridge Trails Committee oversees the development and design of all trails in Sturbridge and provides guidance for the trail widths, finishing materials, parking lot sizes and maintenance requirements.

The Sturbridge Conservation Commission must approve all development projects to insure minimal negative environmental impact and also provides guidance for culvert design and parking lot stormwater best management practices. The Conservation Commission also handles the Wetlands Protection Act.[vi] To find out if a planned development is going to interfere with wetlands a Request of Determination of Applicability (RDA) must be filed with the conservation commission. If the planned development is applicable then a Notice of Intent (NOI) must be filed with the state. Once all the conditions are met a Request for Certificate of Compliance can be submitted to the Conservation Commission before the planned development can proceed.[vii]

The Grand Trunk Trailblazers is a nonprofit organization to promote and assist in the creation of the Titanic Rail Trail across town boundaries.[viii] Their suggestions will guide the design of the Sturbridge trail site to insure that it can be properly connected to trail segments in other towns and to standardize the trail across the town boundaries. The regional trails committee also has the task of encouraging and standardizing trail planning and construction within the region.[ix]

The final recommendations for a project in Sturbridge will first be presented to the Town administrator for approval to then brought to the Sturbridge Trails committee to insure that the plans meet the local trail requirements and are satisfactory to the recommendations of the committee and public. Once the plans for a project are approved by both the Town Administrator and the Sturbridge Trails Committee they can be brought to the Sturbridge Conservation Commission to insure that they meet all environmental regulations and the guidelines of the commission to insure minimal negative environmental impact. Once the plan for the project is approved it can be permitted and then funding can be allocated to begin the execution of the plans and the construction of the project.

Capstone Design

This project will meet the design constraints as determined by the Accreditation Board for Engineering and Technology (ABET) to meet the requirements of the capstone design experience for the Major Qualifying Project. ABET General Criterion 3.(c) states "[Engineering programs must demonstrate that their students attain] an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability."[x]

Economic

This project will incorporate several economic considerations. Cost estimates will be developed for trail and parking lot materials including gravel, loam, and gates. Additionally, each culvert design provided will be rated based on cost estimates of necessary building materials including concrete, rebar, and guard rails. Projected maintenance and upkeep costs for the trail will also be considered and included in the project.

Environmental

The project will include designs for an open-bottomed culvert in compliance with Conservation Commission ordinances and bylaws for wildlife habitat preservation. The culvert will be appropriately designed and sized for a 100-year storm. The parking lot and storage areas will be designed to minimize their impact on the surrounding environment with a specific focus on stormwater runoff control. All trail, parking lot, and culvert plans will be designed to comply with the Wetlands Protection Act.

Sustainability

One of the most important considerations for this project is the sustainability of the trails to allow for continued usage and enjoyment by the people of Sturbridge and surrounding towns. Sustainability issues to be addressed will include appropriate trail design to minimize or prevent the wash-out of trail materials, and culvert designs that incorporate flow calculations for a 100-year flood situation. Also taken into account will be the ease of access to the trails for necessary maintenance vehicles and equipment for mowing or refinishing the trail surfaces and shoulders.

Constructability

The constructability of the project will be hindered by its woodland nature. Special considerations will be made to ensure feasible access to the site by construction vehicles. Because of this, special care must be taken to find ways to minimize the impact of construction on the surrounding nature. This will include selecting a suitable area for storage of materials brought to or excavated from the site that will be of least impact to the surrounding environment. A level parking area will be designed while avoiding any protected wetlands on the site.

Figure 9: Proposed parking area west of trail entrance, showing existing hillside

Ethical

This Major Qualifying Project will be conducted in accordance to the American Society of Civil Engineers Code of Ethics. The Code of Ethics Fundamental Principles states that "engineers uphold and advance the integrity, honor and dignity of the engineering profession by: using their knowledge and skill for the enhancement of human welfare and the environment;

being honest and impartial and serving with fidelity the public, their employers and clients; striving to increase the competence and prestige of the engineering profession; and supporting the professional and technical societies of their disciplines."[xi] This project will strive to provide the best solutions possible to the parties involved, and will not convey any falsified information or violate any regulations of the governing bodies. This includes but is not limited to the ADA and Wetlands Protection Act.

Health and Safety

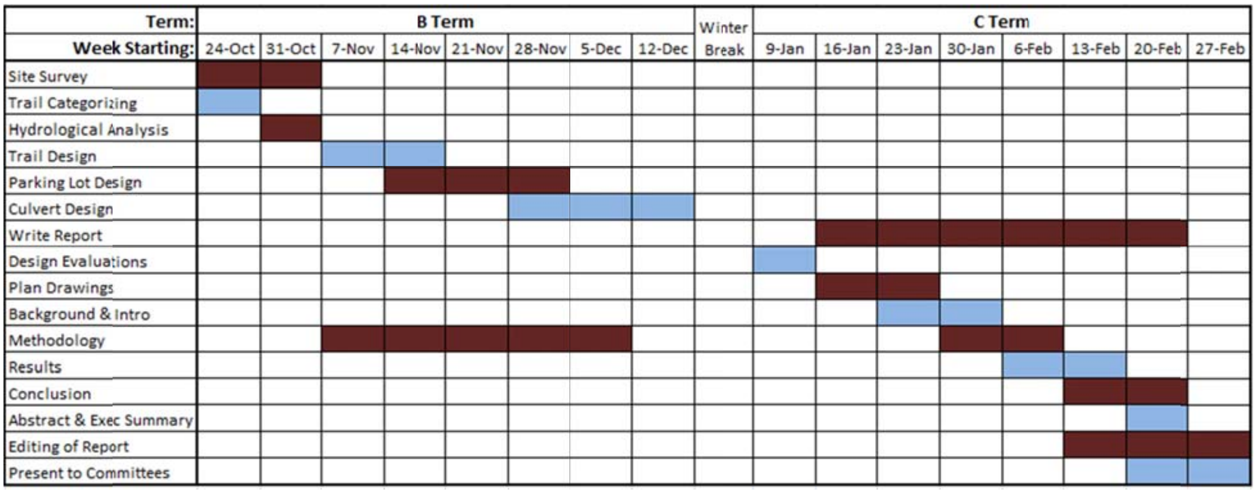
The Town of Sturbridge would like to accommodate multi-use of their trail system including bicycles, wheelchairs, and equestrian usage. The trail designs of this project will be compliant with all applicable Americans with Disabilities Act (ADA) regulations. These include section 4.3 Accessible Routes and section 4.8 Ramps of the ADA Accessibility Guidelines. Since the culvert is to be designed as a load-bearing bridge for pedestrians as well as vehicles, extensive structural integrity tests will be included in the culvert designs to assure human safety.

Social and Political

The site that is the focus of this project is owned by the Town of Sturbridge, as such all design proposals will be presented to the Town Administrator for the Town of Sturbridge for approval. The design proposal will also be presented to the Sturbridge Trails Committee for their approval as the governing body on the trail system within the town. The final design proposal will also be presented to the Conservation Commission for a notice to proceed with work. The project group will work closely with the contacts from the Sturbridge Trails Committee to ensure that all design specifications are met to the satisfaction of the committee.

Methodology

Schedule



Hydrological Analysis

Hydrological analysis will be performed for the wetland area that the site is on. This will include flow calculations based on a 100-year design storm. These calculations will then be used in the designs of the culvert and parking lot.

Surveying

A land survey will be conducted for the design of the trail and parking lot. Surveyed distances will aid in dividing the length of the trail into categorized sections based on their characteristics. The survey will be used to calculate grades on the trail path to ensure ADA requirements are met. The survey of the parking lot area will help determine the boundaries of the parking lot design as well as aid in designing stormwater runoff controls for the parking lot.

Culvert Design

Two designs of culverts will be created to replace the washed-out culvert on the site. The designs will be open-bottomed concrete culverts and they will be designed to meet AASHTO H-20 design load standards. The designs will also feature guardrails for safety requirements and meet the specified finished trail width within the guardrails.

Parking Lot Design

Two designs for trail-head parking lots will be created. The parking lots will be designed to accommodate 20 to 30 vehicles and with considerations to equestrian trailers. Stormwater runoff best management practices will be used when designing the gradation of the parking area. The affect of the parking lot on the surrounding environment will attempt to be minimized in the designs.

Trail Design

A finished trail will be designed for the length from the entrance at Stallion Hill Rd to the gravel pit following the path designated by the Sturbridge Trails Committee. The trail will be designed with the MassHighway "Shared Use and Greenways" design criteria in mind, as well as the established design criteria for other portions of the Grand Trunk Trail.

Geographic Information Systems

Use of Geographic Information Systems (GIS) data will be incorporated into this Major Qualifying Project. ESRI ArcGIS software will be used to develop maps of the Sturbridge trail site to aid in dividing the trail into sections. GIS will also be used to create visual aids to better convey objectives throughout the MQP process.

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[i] http://pugetsoundblogs.com/waterways/files/2010/07/Chico.jpg

[ii] http://t0.gstatic.com/images?q=tbn:u-ps-elbcpdN3M:http://www.meted.ucar.edu/hydro/basic/Runoff/media/graphics/culvert.jpg&t=1
[iii] http://www.grandtrunktrailblazers.org/images/outline-map-Yellow.png
[iv] http://www.grandtrunktrailblazers.org/
[v] http://www.town.sturbridge.ma.us/Public_Documents/SturbridgeMA_Admin/index
[vi] http://www.town.sturbridge.ma.us/Public_Documents/F0000F0EB/Conservation
[vii] http://www.town.sturbridge.ma.us/Public_Documents/F0000F0EB/permits/index
[viii] http://www.grandtrunktrailblazers.org/
[ix] http://www.town.sturbridge.ma.us/Public_Documents/SturbridgeMA_RegionalTrails/index
[x] http://www.abet.org/Linked%20Documents-UPDATE/Criteria%20and%20PP/E001%2009-10%20EAC%20Criteria%2012-01-08.pdf
[xi] http://www.asce.org/Content.aspx?id=7231#note_2

Appendix B – Preliminary Designs Presentation

Riverlands Trail

WPI Trails Project Team
Devon Ward & Walter Woodington
January 13, 2011

Agenda

- Design Goals
- Trail
- Parking Lot
- Culvert

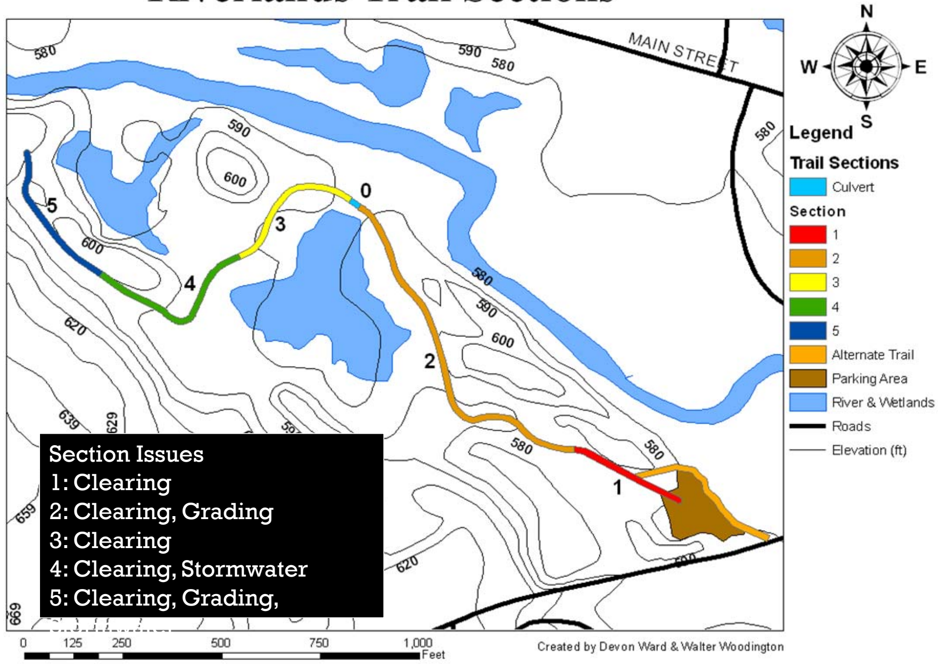
Assumed Design Criteria

- Trail
  - ADA Compliance (entirely <5% grade)
  - Stormwater/Erosion Controls
  - 10' wide finished grade with 2' and 4' shoulders
- Parking Lot
  - 25 Cars, 2 Horse Trailers
  - Maintenance Area
  - Stormwater Collection
- Culvert
  - 100 Year Design Storm
  - Guardrails
  - Accommodate Logging Trucks
  - Open Bottom

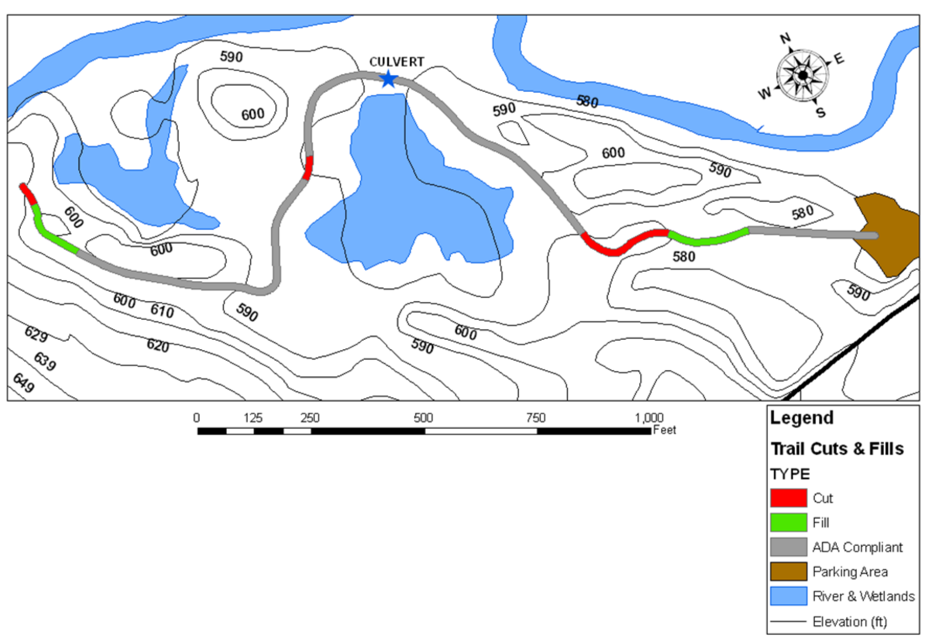
Trail

- Trail Survey Completed
  - 2512 ft of Trail to be Designed
- Existing Issues Categorized and Sectioned
  - Grading (Areas >5% Grade)
  - Stormwater/Erosion Problems (scouring, flows)
  - River Buffer (200' from bank to trail center line)
  - Clearing

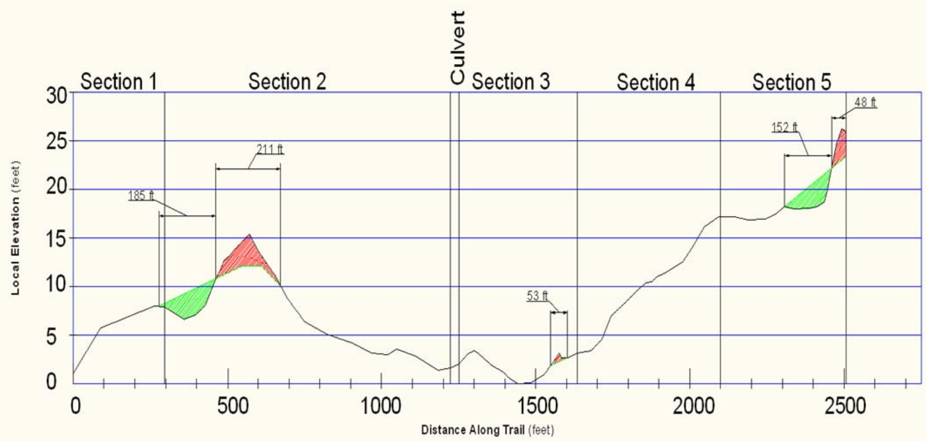
Riverlands Trail Sections



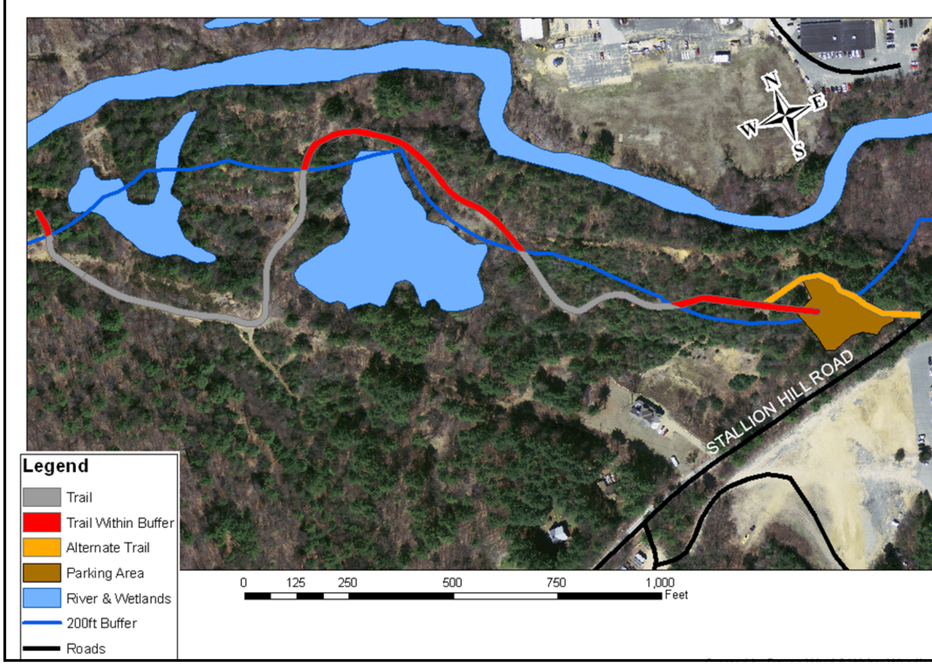
Riverlands Trail Cuts & Fills



Trail Elevation Model



Riverlands Trail within 200ft River Buffer



Trail: Remaining Questions

- Finished trail width?
  - 10' wide with 2' and 4' buffers?
  - Affects cost of materials & clearing
  - Should match Grand Trunk Trail
- Stormwater controls preference?
  - Waterbars? Grade dips? Handicap friendly?
- Trail is within 200' buffer of wetlands and river
  - Permitting issues?

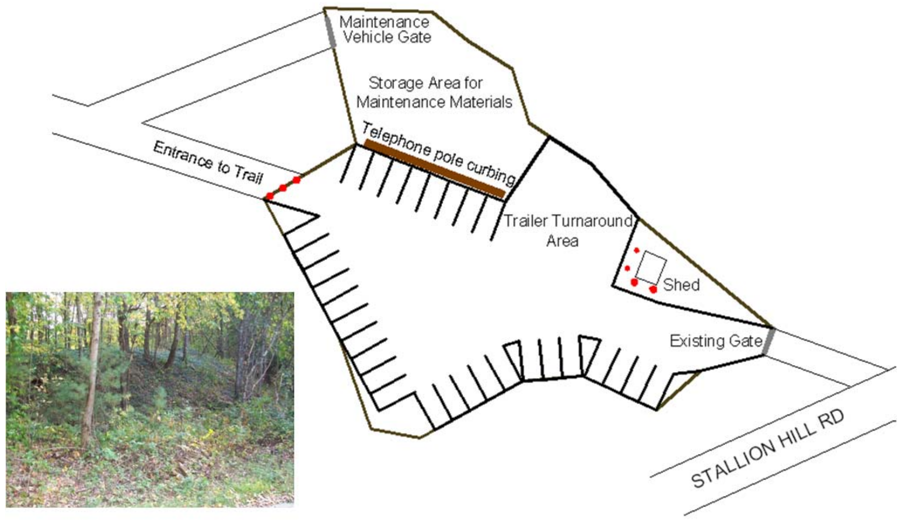
Parking Lot

- Surveyed the usable area without requiring hillside excavation
- Two preliminary design alternatives created

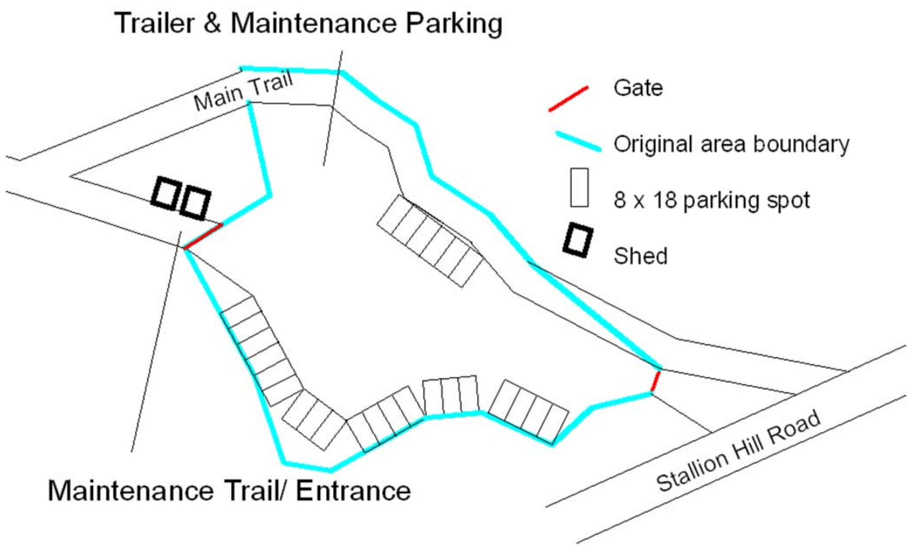

Trail Entrance from Stallion Hill Rd


Existing Storage Shed at Trailhead

Parking Lot: Alternative #1



Parking Lot: Alternative #2



Parking Lot: Preliminary Designs

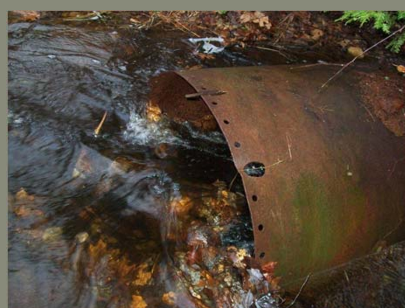
Requirement	Alternative #1	Alternative #2
Storage Shed Undisturbed	✓	
Light Pole Undisturbed		
Separate Walking Trail		✓
No Excavation	✓	
Maintenance Area	✓	✓
Trailer Turn-around	✓	✓
Parking Capacity	30	26

Parking Lot: Remaining Questions

- Expected usage
  - Number of cars or horse trailers?
- Can the storage shed be moved?
- Rewire or remove the existing light pole?
- Can the trail pass through parking lot?

Culvert

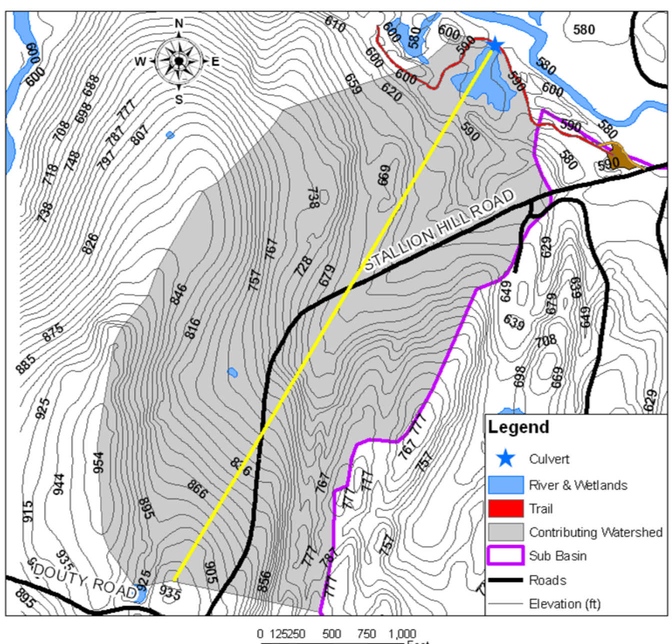
- Contributing watershed delineated
- Hydrological analysis
- 100 Year Storm flow calculation



Existing Culvert

Upstream of Culvert towards Wetlands

Contributing Watershed Area



Culvert: Watershed Details

Culvert under Power lines

Wetlands Upstream from
Washed-out Culvert

Culvert: Flow Summary

- Observed storm, Nov. 17
  - Rainfall = 1.16 in / 24 hr
  - < 1 yr Design Storm
  - Measured Flow = 11 to 13 cfs
- Design Storm Calculations
  - 100 yr Design Storm
  - Rainfall = 6.5 in / 24 hr
  - Peak flow = 84 cfs

Culvert: Questions

- Precipitation data for Oct. '05 flood?
- What design storm should be used?
- Load rating?
  - Logging Trucks?

Project Goals

- Preliminary engineering designs for trail, parking lot, and culvert
- Presentation of design alternatives
- Cost analysis
- Final design recommendations based on evaluation criteria

Appendix C – Final Designs Presentation

Riverlands Trail Design Recommendations

WPI Trails Project Team
Devon Ward & Walter Woodington
April 14, 2011

Agenda

- Design Goal
- Trail
  - Design Criteria + Process Summary
  - Trail Cross Section
  - Grading
  - Stormwater Management
  - Trail Near Protected Area
  - Cost Estimation
- Parking Lot
  - Design Criteria + Process Summary
  - Stormwater Management + Cross Section
  - Layouts and Storage
  - Cost Estimation
  - Evaluation of Alternatives
- Culvert
  - Design Criteria + Process Summary
  - Cross Sections
  - Cost Estimation
  - Evaluation of Alternatives
- Cost Summary

Design Goal

Recreational trails can be a valuable part of a community. Dedicated and well maintained trail systems offer a variety of recreational activities to local residents, including hiking, mountain biking, and horseback riding. Properly graded trails can also provide disabled residents access to nature and outdoor recreation that otherwise may not be possible. These unpaved trails create a wealth of opportunities for physical activity, expose people to natures' beauties, and if designed properly can have a minimal impact on the environment.

The goal of this project was to present solutions to the issues preventing the Riverlands Trail from being officially recognized, widely used by the residents of Sturbridge, and its future integration into the Titanic Rail Trail.

Trail

- Trail
  - Design Criteria + Process Summary
  - Trail Cross Section
  - Grading
  - Stormwater Management
  - Proximity to Protected Area
  - Cost Estimation

Site Visit Photos

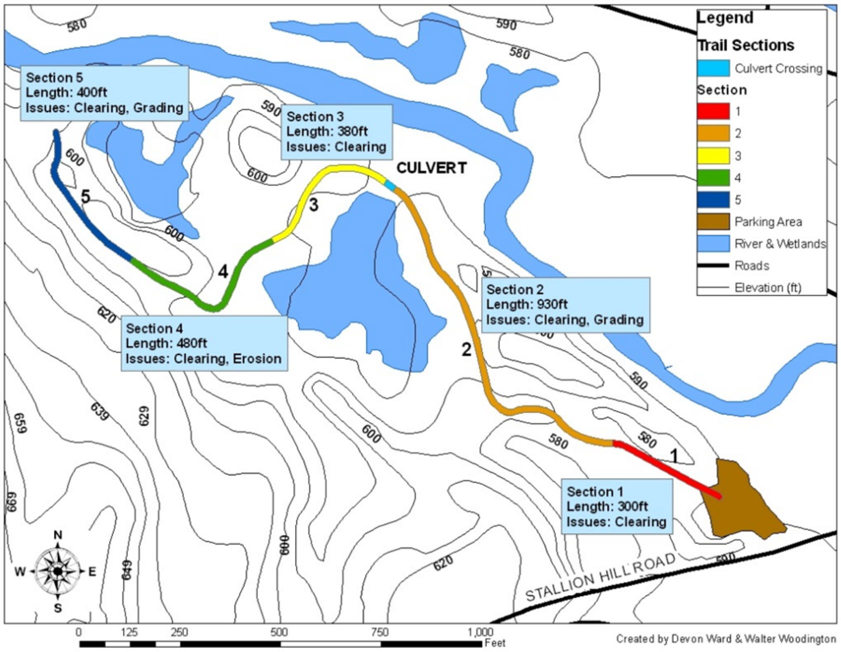
Trail Design Criteria

Design Area	Source	Requirement
Trail Cross Section	Titanic Rail Trail Standard	10 foot main trail 2 and 4 foot shoulders
Grading	Americans with Disabilities Act (ADA)	Maximum 5% grade for 200 feet Maximum 8% grade for 80 feet
Stormwater Controls	Sturbridge Trails Committee	User safety Low Maintenance
Development Near Protected Wetlands	Mass. Wetlands Protection Act	New Development should not interfere with vegetation or wild life.
Development Near Protected River	Mass. River Protection Act	200 foot buffer between river and trail

Trail Design Process

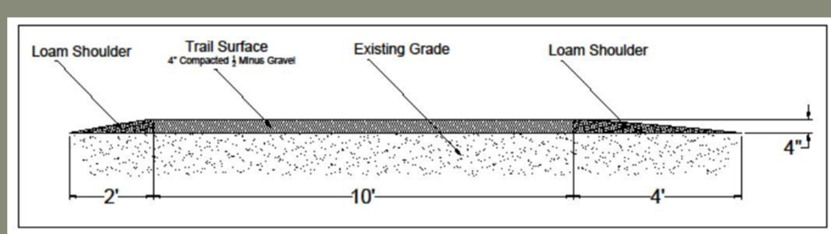
1. Extensive site survey
2. Categorization of issues
3. Division of trail into sections
4. Four main categories of issues:
   - Trail Clearing
   - Grading
   - Stormwater Controls
   - Proximity to Protected Areas

Riverlands Trail Sections



Trail Cross Section

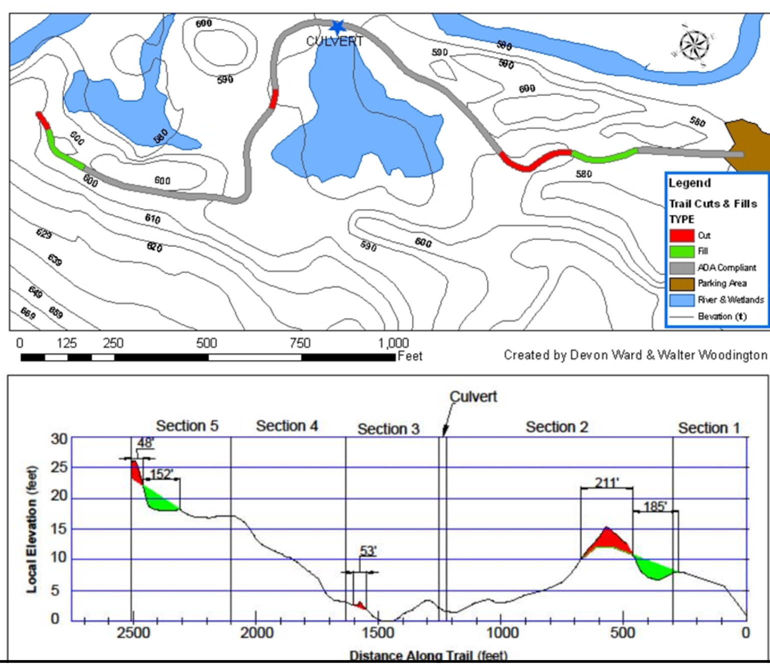
- Trail width and surface were designed to meet the Titanic Rail Trail standard.



Trail Grading

- Elevation data was used to determine required excavation and fill to comply with the ADA.
- Excavation volume designed to be equal to fill Volume.

Riverlands Trail Cuts & Fills



Stormwater Controls

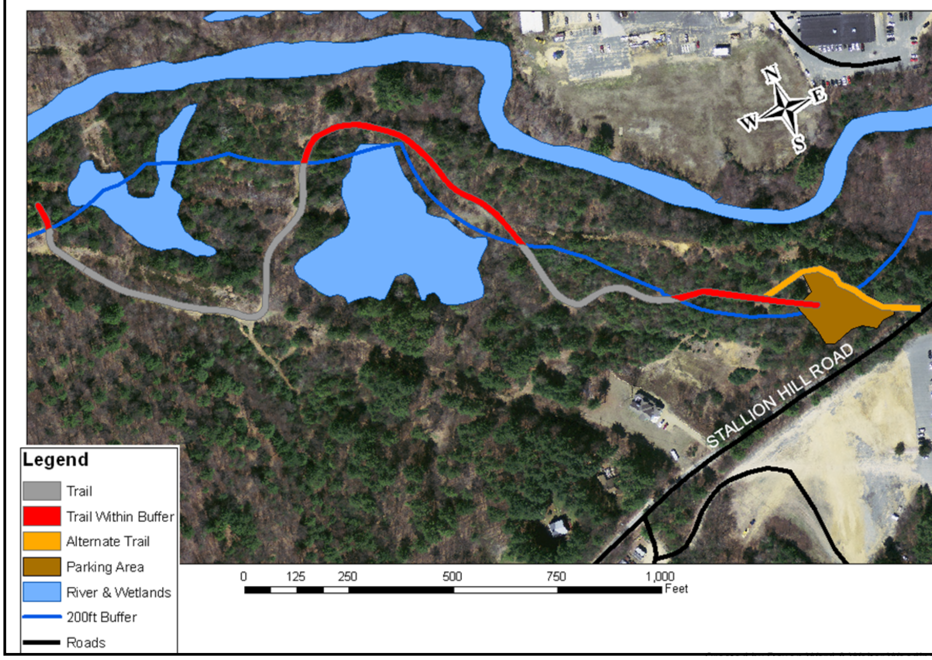
- Comparison of alternatives:
  - Grade Dips
  - Water Bars
  - Cross Grade
- Grade dips recommended.
  - Easier to maintain
  - Accessibility
    - Wheelchairs
    - Bicycles

Grade Dip Example
http://www.fhwa.dot.gov/environment/fspubs/00232839/figure19.jpg

Proximity to Protected Areas

- Most of the trail is within the protected areas of wetlands or riverbank.
- Excessive development in protected areas was avoided in design.
- Special permitting will be required.

Riverlands Trail within 200ft River Buffer



Trail Cost Estimation

- ½ " Minus Process Gravel: 345 Cu. Yds.
- Cost: $17.50 per Cu. Yd.
- Total Cost: $6040

Parking Lot

- Parking Lot
  - Design Process Summary
  - Stormwater Management/ Cross Section
  - Layouts and storage
  - Evaluation of Alternatives
  - Cost Estimation

Trail Entrance from Stallion Hill Rd

Existing Storage Shed at Trailhead

Parking Lot Design Criteria

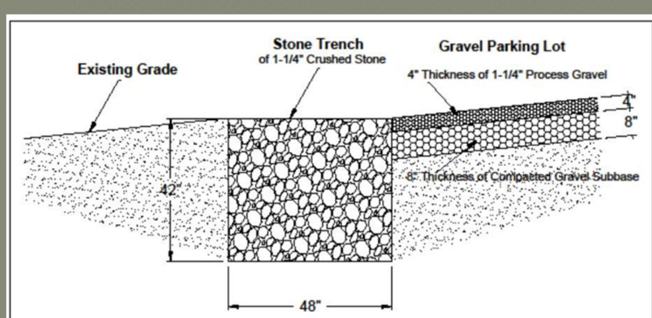
Design Area	Requirement
Capacity	25-30 Vehicles Horse Trailer Parking ADA Compliant Spaces
Vehicle Controls	Maintenance Vehicle Gate Bollard Barriers
Safety	Separated Trailer Turn-around Area Separate Trail Entrance
Stormwater Controls	Cross Grading Gravel Trench

Parking Lot Design Process

1. A survey was performed to determine the level, clear space existing at the entrance to the site.
2. Survey points were imported into AutoCAD and ArcGIS.
3. Two preliminary parking lot designs were created to incorporate different aspects of the preliminary design criteria.
4. Preliminary designs were presented for feedback and revisions.
5. Two final designs were created based on the gathered feedback.

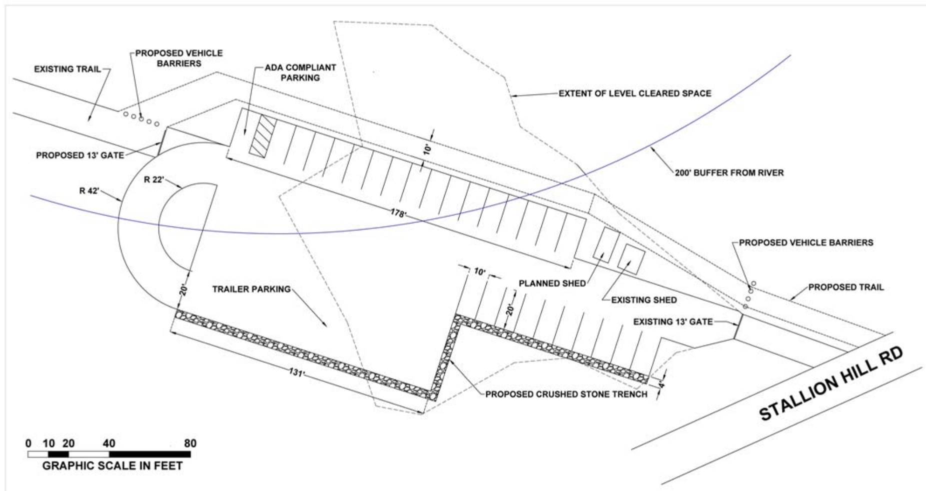
Stormwater BMP + Cross Section

- A gravel infiltration trench and the gravel parking lot cross section were based a design for a similar project in Sturbridge

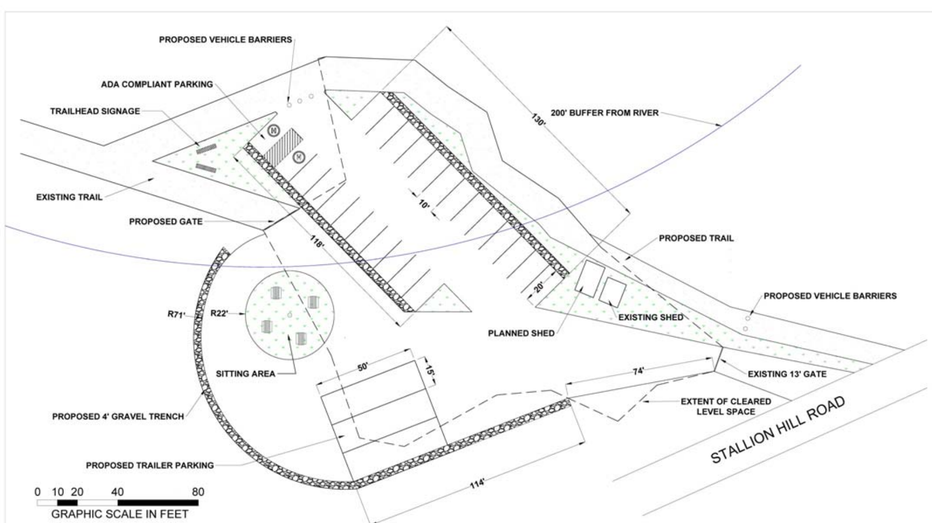


Gravel Infiltration Trench & Parking Lot Cross Section

Parking Lot: Alternative #1



Parking Lot: Alternative #2



Cost Estimation

- Alternative #1
- Process Gravel
  - Cubic Yards: 278
  - Cost per cu yd. $17.50
  - Total: $4870
- Subbase
  - Cubic Yards: 557
  - Cost per cu yd. $10.00
  - Total: $5570
- Trench
  - Cubic Yards: 140
  - Cost per cu yd. $10.00
  - Total: $1400
- Total: $12,000

- Alternative #2
- Process Gravel
  - Cubic Yards: 305
  - Cost per cu yd. $17.50
  - Total: $5340
- Subbase
  - Cubic Yards: 611
  - Cost per cu yd. $10.00
  - Total: $6110
- Trench
  - Cubic Yards: 261
  - Cost per cu yd. $10.00
  - Total: $2610
- Total: $ 14,250

Evaluation of Alternatives

DESIGN ALTERNATIVE #1

- Less materials
- More parking (27 spaces)
- Straight entrance for maintenance vehicles
- Rectangular parking layout
- Less hillside excavation
- Simple grading
- Less distance between horses and other users
- No property line conflict

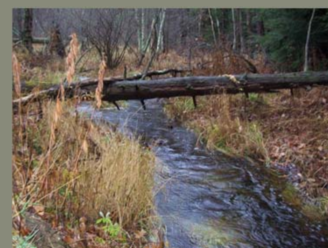
DESIGN ALTERNATIVE #2

- More materials
- Less parking (24 spaces)
- Efficient use of existing clear, level space
- Larger area for horse trailers
- More hillside excavation
- Complex grading
- Safer distance for horses from other trail users
- Possible property line confliction

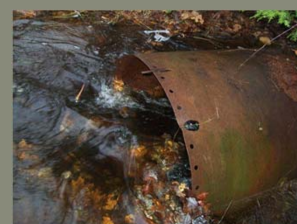
Final design recommendation: Design Alternative #1

Culvert

- Culvert
  - Design Process Summary
    - Hydrological Calculations
  - Cross Sections
  - Evaluation of Alternatives
  - Cost Estimation



Upstream towards Wetlands



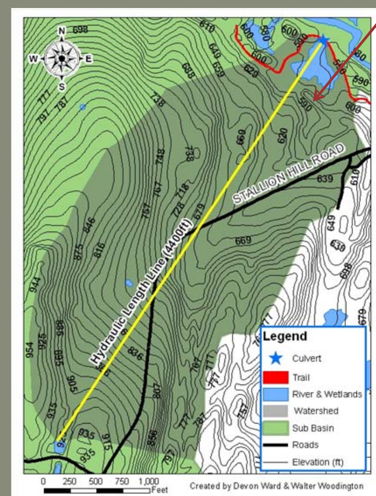
Existing Culvert

Culvert Design Criteria

Design Area	Source	Requirement
Topography	MassGIS Contours	Available Storage Volume = 137,700sq.ft. x 5ft = 688,500 Cubic Feet
Design Storm	Sturbridge Trails Committee Meetings	Culvert should handle peak flows for a 25-year rain event.
Hydrology	Hydrological Analysis	Contributing Watershed Hydrograph Peak Culvert Inflow = 136 CFS
Max Live Loads	Sturbridge Trails Committee Meetings	Logging trucks should be accommodated. Highway 20 Rating
Geometry	Site Visits	Streambed to Trail Height = 6 Feet

Culvert Design Process

1. Contributing watershed created in ArcGIS from MassGIS data.
2. Hydrological calculations for a 25-year storm were performed using methods from the NRCS TR-55 manual.
   - The Graphical Peak Discharge Method yielded a peak flow of 136cfs
   - The Tabular Hydrograph Method produced a hydrograph for culvert inflow.
3. Storm (Worc. Airport) and flow data were collected (Nov. 17, 2010) and used to verify hydrological calculations.



Contributing Watershed Area

Watershed Details

Culvert under Power lines

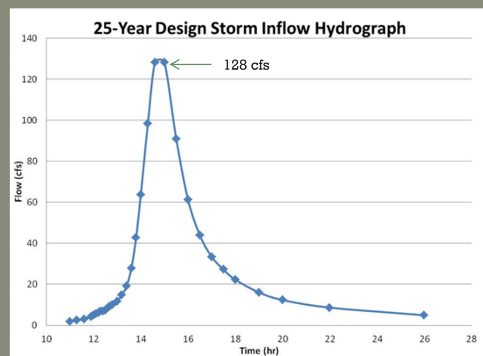
Wetlands Upstream from Washed-out Culvert

Culvert Design Process Cont.

4. Pipe and box culvert alternatives were selected.

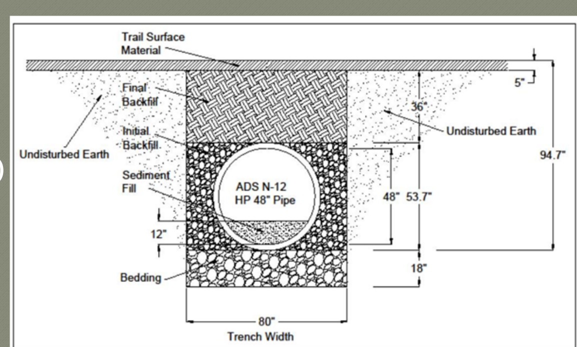
5. Hydraulic calculations sized the alternatives to accommodate flow for two limiting cases:
   - Inflow Limited (Orifice Flow Equation)
   - Energy Loss Limited (Energy Balance Equation)

6. Structural designs were based on manufacturer (ADS) recommendations.



Pipe Culvert Cross Section

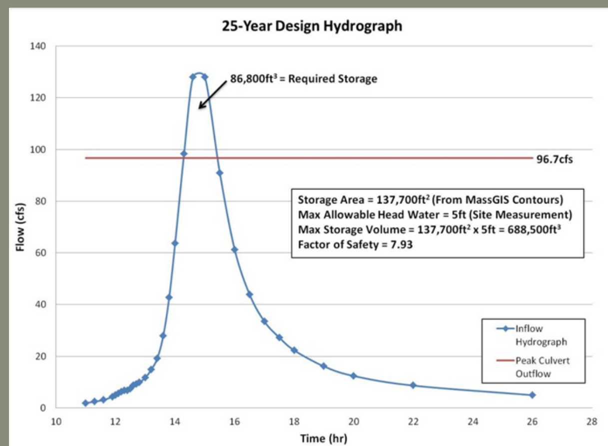
- ADS Design Guide:
  - Cover Depth
  - Trench Width
  - Soil Layers
- Concrete rubble armoring (Riprap)
- 3:1 side slope
- Length = 34’
  - Standard Trail
  - Side Slope
  - Guardrails



Pipe Culvert Cross Section

Pipe Culvert Storage

- Required storage was calculated from inflow/outflow hydrograph.
- Then checked against the available storage of the wetland area, determined using ArcGIS and MassGIS contour lines.



Pipe Installation Example

~24" Corrugated Plastic Pipe Culvert

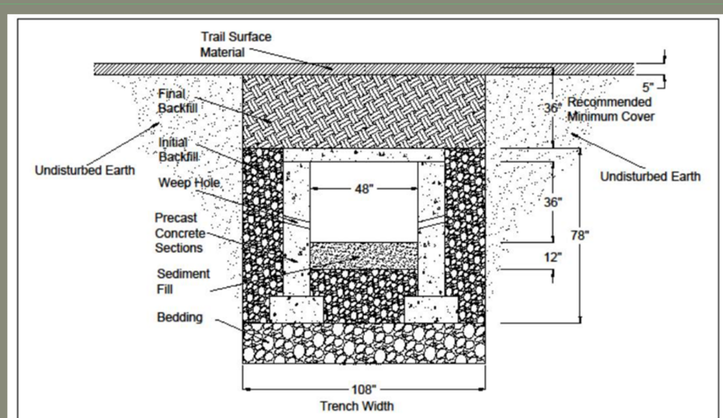
http://www.marietta.edu/~biol/field_station/images/construction/culvert_1147.jpg

Pipe Installation Example

Large Corrugated Plastic Pipe Culvert

http://www.marietta.edu/~biol/field_station/images/construction/culvert_1053.jpg
http://www.marietta.edu/~biol/field_station/images/construction/culvert_1127.jpg

Box Culvert Cross Section



Box Culvert Cross Section Preliminary Design

Box Culvert Properties

- Concrete rubble armoring (Riprap)
- 3:1 side slope
- Length = 34'
  - Standard Trail
  - Side Slope
  - Guardrails
- Hydraulic Design
  - Zero Storage justified by cost of construction
- Structural Design
  - Recommended Cover = 36"
- Box culvert not recommended so concrete reinforcing has not been designed.

Pipe Culvert Cost Estimation

- ADS 48" N-12 HP Pipe
- Cost per foot = $70 (High Estimate)
- Culvert Pipe Cost= $2,380

Evaluation of Alternatives

PIPE CULVERT

- Simpler and less intrusive construction
- Lower Cost
- Sediment filled bottom
- Simpler Design

BOX CULVERT

- Intrusive construction
  - Wider and deeper trench
- Higher Cost
- Natural bottom
- Complicated design

Final Recommendation: Pipe Culvert

Cost Summary

- Total estimated cost of materials for design recommendations:
- Trail = $6,040
- Parking Lot = $12,000
- Culvert = $2,380
- <u>TOTAL = $20,420</u>

- Final documents will be made available online in early May
- Presentation will be e-mailed following meeting